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Characterization of MWC (Municipal Waste Combustion) Ashes and Leachates from MSW (Municipal Solid Waste) Landfills Monofills, and Co-Disposal Sites. Volume 4

NUS Corp., Pittsburgh, PA

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Characterization of MWC Ashes and Leachates from MSW Landfills, Monofills, and Co-Disposal Sites

Volume IV of VII

Characterization of Muncipal Waste Combustion Residues and Their Leachates—A Literature Review

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VOLUME IV OF VII

Prepared for

U.S. ENVIRONMENTAL PROTECTION AGENCY
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1-1 Gross MSW Disposed, Materials Recovery, Energy Recovery, and New MSW Disposed, 1960 to 2000 1-2

ACRONYMS AND DEFINITIONS

BNA	Base-neutral and Acid Extractables
BOD	Biological Oxygen Demand
CAS	Chemical Abstract Service
CB	Chlorobiphenyl
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
COD	Chemical Oxygen Demand
Codisposal	Disposal together of municipal solid wastes and municipal solid waste combustion ashes
CP	Chlorinated Phenols
DWE	Deionized Water Extraction Test Method
EP	Extraction Procedure
EPA	U.S. Environmental Protection Agency
ESP	Electrostatic Precipitator
HSWA	Hazardous and Solid Waste Amendments
HWC	Hazardous Waste Combustion
LF	Landfill
MCL	Maximum Contaminant Level
Monofill	A landfill that contains only solid waste combustion ashes and residues
MSW	Municipal Solid Waste
MW	Monitoring Well
MWC	Municipal Waste Combustion
MWEP	Monofilled Waste Extraction Procedure, also known as SW-924
ND	Not Detected
NPDES	National Pollutant Discharge Elimination System
PAHs	Polynuclear Aromatic Hydrocarbons
PCBs	Polychlorinated Biphenyls

ACRONYMS AND DEFINITIONS
PAGE TWO

PCDDs	Polychlorinated dibenzo-p-dioxins
PCDFs	Polychlorinated dibenzofurans
POTW	Publically Owned Treatment Works
RCRA	Resource Conservation and Recovery Act
RDF	Refuse Derived Fuel
RPD	Relative Percent Difference
SS	Suspended Solids
SW-924	Deionized Water Extraction Test Method
TCLP	Toxic Characteristics Leaching Procedure Test Method
TDS	Total Dissolved Solids
TEF	Toxic Equivalency Factors
TNK	Total Nitrogen Kjeldahl
TOC	Total Organic Carbon
TSCA	Toxic Substances Control Act

1.0 INTRODUCTION

There has been a steady decrease in space available for municipal solid waste (MSW) disposal in recent years. Therefore, there is an increased concern by local, state, and Federal governments and the public about identifying and implementing alternatives for reducing the volume of MSW by means that are compatible with environmental, economic, and social factors.

Projections indicate that although an increase in MSW generation is anticipated, the actual volume will not grow, but rather will stabilize. This stabilization results from the increase of material recovery from MSW and the implementation of incineration to produce energy and to reduce waste volume. Figure 1-1 illustrates these projections through the year 2000.

Since incineration is one of the primary means of reducing the volume of MSW, it becomes necessary to assess the environmental, economic, and social consequences of this alternative as measured by benefits and costs. The U.S. Environmental Protection Agency (EPA), under mandate from the U.S. Congress, is in the process of performing various studies to provide input for the overall evaluation of MSW incineration, its benefits, and costs.

This report consists of a review of pertinent literature and the results of research recently conducted for the EPA. Volume V of this report covers the results of this research in greater detail. These data address environmental issues associated with contaminant discharges from MWC residues into environmental media. Specifically, this report addresses the potential discharges of leachates into soil, groundwater, and surface water. Leachable residues of concern are fly ash, bottom ash, and combined ash (fly and bottom mixed). This report describes the chemical characteristics of fly ash, bottom ash, and combined ashes, as well as the characteristics of extracts and leachates.

MSW consists of residential, commercial, and institutional wastes. Its composition varies widely. Table 1-1 illustrates the material composition of disposed MSW and the projected volume increase by year 2000. The data presented in Table 1-1

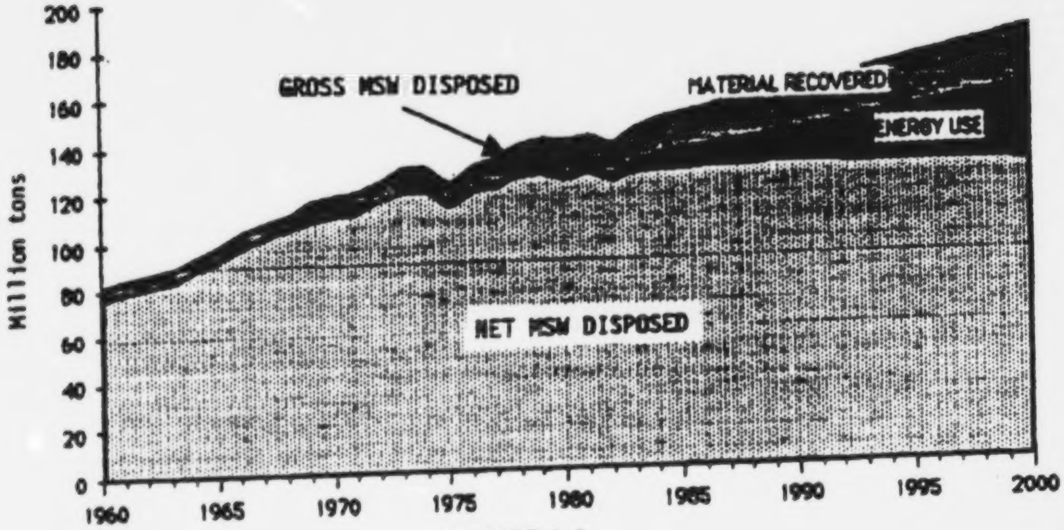

FIGURE 1-1

GROSS MSW DISPOSED, MATERIALS RECOVERY, ENERGY RECOVERY, AND NEW MSW DISPOSED, 1960 TO 2000

Source: PRC Engineering (Reference 50)

TABLE 1-1

MATERIALS DISPOSED INTO THE MUNICIPAL WASTE STREAM
(In Millions of Tons and Percent)

Materials	1970		1984		2000	
	Tons	%	Tons	%	Tons	%
Paper and Paperboard	36.5	33.1	49.4	37.1	65.1	41.0
Glass	12.5	11.3	12.9	9.7	12.1	7.6
Metals	13.5	12.2	12.8	9.6	14.3	9.0
Plastics	3.0	2.7	9.6	7.2	15.5	9.8
Rubber and Leather	3.0	2.7	3.3	2.5	3.8	2.4
Textiles	2.2	2.0	2.8	2.1	3.5	2.2
Wood	4.0	3.6	5.1	3.8	6.1	3.8
Other	----	0.1	0.1	0.1	0.1	0.1
Food Wastes	12.7	11.5	10.8	8.1	10.8	6.8
Yard Wastes	21.0	19.0	23.8	17.9	24.4	15.3
Miscellaneous Inorganic Wastes	1.8	1.6	2.4	1.8	3.1	2.0
TOTAL	110.3	100.0	133.0	100.0	158.8	100.0

Source: PRC Engineering (Reference 50)

clearly show a high percentage of combustible products, such as paper and paperboards, a percentage which increases steadily with time. Also shown are materials that could cause the discharge of hazardous and toxic contaminants during incomplete combustion. These include plastics, rubber, textiles, and yard wastes. Table 1-2 is a summary of the MSW incinerator statistics described in this recent study.

The objective of this study was to review the appropriate literature generated in the United States, Canada, Japan, and Europe and to provide the following information:

- The range of concentrations of organic and inorganic constituents in fly ash, bottom ash, and combined ash.
- The degree of leachability of organic and inorganic constituents from ashes, based on simulated leachate studies (EP toxicity, TCLP, and deionized water - SW-924 test procedures) and on leachate characterization from landfills that dispose only of MWC ashes.

A total of 65 references were reviewed under this project. Reference 63 contains the results of a study recently undertaken by Versar for EPA. The Versar Study appears in its entirety in Volume V of this report. The list of reviewed references is included in the reference section (Section 6.0).

The data obtained can be evaluated and used in assessing the potential environmental effects of leachates from disposal ashes. Subsequent mitigating measures can be developed, if necessary.

Section 2.0, Characterization of Ashes, provides data and information on the concentration of organic and inorganic constituents in ashes from MSW incinerators.

TABLE 1-2

SUMMARY OF MSW INCINERATOR STATISTICS

	Total	Modular	Conventional	RDF
Total facilities operating number	102	51	48	3
With heat recovery	55	31	24	NA
Total MSW Managed (Ton/Day)	33,541	5,296	26,018	2,227
Total Ash Generated				
a. Ash Disposed	7,547	1,943	5,374	231
b. Dry-weight Basis	5,191	965	4,027	199
c. Bottom Ash as Disposed	2,930	1,630	1,175	125
d. Fly Ash as Disposed	361	143	114	105
e. Combined Ash as Disposed	4,255	169	4,085	0
Number of Facilities				
a. Disposal Method				
1. Onsite Landfill	23	12	9	2
2. Offsite Landfill	73	36	36	1
3. Other/Unknown	6	3	3	0
b. Type of Landfill				
1. Monofill	36	16	18	2
2. Codisposal	41	19	21	1
3. Other/Unknown/Not LF	25	16	9	0
Ash Disposed Of:				
a. Disposal Method				
1. Onsite Landfill	22.78%	3.37%	28.61%	50.39%
2. Offsite Landfill	77.22%	96.63%	71.39%	49.61%
3. Other/Unknown	0.00%	0.00%	0.00%	0.00%
b. Type of Landfill				
1. Monofill	35.50%	25.97%	38.30%	50.39%
2. Codisposal	17.45%	46.14%	5.70%	49.61%
3. Other/Unknown/Not LF	46.57%	27.89%	55.32%	0.00%

Source: Engineering Science (Reference 24)
RDF = Refuse Derived Fuel
LF = Landfill

Section 3.0, Characterization of Extracts, addresses concentrations of organic and inorganic constituents in leachates using the following techniques:

- Deionized Water Extraction (DWE) test method (SW-924)
- Extraction Procedure (EP) test method
- Toxic Characteristic Leaching Procedure (TCLP) test method

Section 4.0, Characterization of Leachate from Field Samples, provides data and information on concentrations of organic and inorganic constituents in samples obtained from field leachates. These leachates were obtained from disposal sites where only MSW ashes are disposed of (i.e., monofills).

Section 5.0, Summary, Conclusions and Recommendations, highlights the findings of this, including identification of data gaps, inconsistencies, and the need for additional data.

2.0 CHARACTERIZATION OF ASHES

A large number of studies have been conducted to characterize ashes from municipal solid waste (MWC). Some of these studies date back to the early 1970s, but most are more recent. Studies conducted in the 1970s and early 1980s in general addressed only concentrations of inorganic constituents in MWC with emphasis on metals. They were conducted in parallel with characterization studies of coal ashes. Recent studies have increased the emphasis of characterizing concentrations of organic constituents in MWC ashes.

These organic constituents include the following:

- Polychlorinated dibenzo-p-dioxins (PCDDs)
- Polychlorinated dibenzofurans (PCBFs)
- Polychlorinated biphenyls (PCBs)
- Polyaromatic hydrocarbons (PAHs)
- Chlorinated phenols (CPs)
- Other organics

The recent emphasis on organic constituents is the result of the increased awareness and concern about their potential health and environmental effects.

This section addresses concentrations of organic and inorganic constituents in ashes (fly, bottom, and combined). It is based on information gathered from studies conducted in the United States and abroad.

2.1 FLY ASH

2.1.1 PDD, PCDF, and PCB Concentrations

Ranges of concentrations of PCDDs, PCDFs, and PCBs in fly ash from MSW incinerators are presented in Table 2-1; Tables 2-2 and 2-3 provide detailed concentrations for each pertinent reference. The salient features of the data provided in Tables 2-1 through 2-3 are as follows:

TABLE 2-1

RANGES OF CONCENTRATIONS OF PCDDs, PCDFs, AND PCBs IN FLY ASH FROM MUNICIPAL WASTE INCINERATORS IN ng/g (ppb)

Constituent	Concentration	References
MCDD	2.0	30
DCDD	0.4-200	30, 64
T_3CDD	1.1-82	30, 64
T_4CDD	ND-250	1, 11, 13, 22, 23, 30, 34, 42, 53, 63, 64
PCDD	ND-722	1, 11, 22, 23, 30, 34, 42, 53, 63, 64
HCDD	ND-5,565	1, 11, 13, 22, 23, 30, 34, 42, 53, 63, 64
H_7CDD	ND-3,030	1, 11, 12, 13, 22, 23, 30, 34, 42, 53, 63, 64
OCDD	ND-3,152	1, 11, 13, 22, 23, 30, 34, 42, 53, 63, 64
2,3,7,8-TCDD	0.1-42	26, 30, 62, 63, 64
Total PCDD	5.23-10,883	1, 11, 22, 23, 26, 30, 34, 42, 53, 62, 63, 64
MCDF	41	30
DCDF	ND-90	30, 64
T_3CDF	0.7-550	30, 64
T_4CDF	ND-410	11, 30, 34, 42, 53, 63, 64
PCDF	ND-1,800	30, 34, 42, 53, 63, 64
HCDF	Tr-2,353	30, 34, 42, 53, 63, 64
H_7CDF	Tr-666	11, 30, 34, 42, 53, 63, 64
OCDF	ND-362	11, 30, 34, 42, 53, 63, 64
2,3,7,8-TCDF	0.1-5.4	64
Total PCDF	3.73-3,187	26, 30, 62, 63, 64
Mono CB	0.29-9.5	30, 63
Di CB	0.13-9.9	30, 63, 64
Tri CB	ND-25	30, 63, 64
Tetra CB	0.5-42	30, 63, 64
Penta CB	0.87-225	30, 63, 64
Hexa CB	0.45-65	30, 64
Hepta CB	ND-0.1	30, 64
Octa CB	ND-1.2	30, 64
Nona CB	ND	30
Deca CB	ND	30
Total PCB	ND-250	26, 30, 62, 63, 64
Country		USA, Canada, West Germany, The Netherlands, Japan

ND = Below detection limit
Tr = $0.01 < Tr < 0.1$ ng/g (ppb)
CB = Chlorobiphenyl

TABLE 2-1

RANGES OF CONCENTRATIONS OF PCDDs, PCDFs, AND PCBs IN FLY ASH FROM MUNICIPAL WASTE INCINERATORS IN ng/g (ppb)

Constituent	Concentration	References
MCDD	2.0	30
DCDD	0.4-200	30, 64
T_3CDD	1.1-82	30, 64
T_4CDD	ND-250	1, 11, 13, 22, 23, 30, 34, 42, 53, 63, 64
PCDD	ND-722	1, 11, 22, 23, 30, 34, 42, 53, 63, 64
HCDD	ND-5,565	1, 11, 13, 22, 23, 30, 34, 42, 53, 63, 64
H_7CDD	ND-3,030	1, 11, 12, 13, 22, 23, 30, 34, 42, 53, 63, 64
OCDD	ND-3,152	1, 11, 13, 22, 23, 30, 34, 42, 53, 63, 64
2,3,7,8-TCDD	0.1-42	26, 30, 62, 63, 64
Total PCDD	5.23-10,883	1, 11, 22, 23, 26, 30, 34, 42, 53, 62, 63, 64
MCDF	41	30
DCDF	ND-90	30, 64
T_3CDF	0.7-550	30, 64
T_4CDF	ND-410	11, 30, 34, 42, 53, 63, 64
PCDF	ND-1,800	30, 34, 42, 53, 63, 64
HCDF	Tr-2,353	30, 34, 42, 53, 63, 64
H_7CDF	Tr-666	11, 30, 34, 42, 53, 63, 64
OCDF	ND-362	11, 30, 34, 42, 53, 63, 64
2,3,7,8-TCDF	0.1-5.4	64
Total PCDF	3.73-3,187	26, 30, 62, 63, 64
Mono CB	0.29-9.5	30, 63
Di CB	0.13-9.9	30, 63, 64
Tri CB	ND-25	30, 63, 64
Tetra CB	0.5-42	30, 63, 64
Penta CB	0.87-225	30, 63, 64
Hexa CB	0.45-65	30, 64
Hepta CB	ND-0.1	30, 64
Octa CB	ND-1.2	30, 64
Nona CB	ND	30
Deca CB	ND	30
Total PCB	ND-250	26, 30, 62, 63, 64
Country		USA, Canada, West Germany, The Netherlands, Japan

ND = Below detection limit
Tr = $0.01 < Tr < 0.1$ ng/g (ppb)
CB = Chlorobiphenyl

TABLE 2-2

CONCENTRATIONS OF PCDDs AND PCDFs IN FLY ASH FROM MUNICIPAL WASTE INCINERATORS IN ng/g (ppb)

Constituent	Reference 34	Reference 1	Reference 42			Reference 22	Reference 53	Reference 11
T_4CDD	ND	9	2.7-6	2.5-12	5-110	3.2-27	3	ND-46
PCDD	ND	15			31-488	3.4-45	20	ND-65
HCDD	0.2-0.4	13			80-1,200	2.2-53	50	ND-2,496
H_7CDD	0.6-2.5	3			190-902	1.1-43	180	0.001-88
OCDD	7.2-20	0.4	0.7-150		106-266	0.4-26	210	0.1-842
Total PCDD						10-170		
T_4CDF	0.8-28				13-223		9	ND-62
PCDF	0.3-8				42 - 510		23	
HCDF	0.4-8				109 - 870		50	
H_7CDF	0.6-10				89-407		250	0.002-255
OCDF	0.3 - 14		0.2 - 166		18 - 26		135	0.002 - 255
Total PCDF								
No. of Samples	3	Not given	Based on 3 Different Incinerators	Based on 5 Different Incinerators	Based on 87 Samples from 25 Incinerators	8	Not given	6 Incinerators
Sample Taken	ESP	ESP	ESP	ESP	ESP	ESP	ESP	Not given
Country	West Germany	Ontario, Canada	Italy	Canada	The Netherlands	Ontario, Canada	Unknown	Italy

ND = Below detection limit
ESP = Electrostatic precipitator
Blank - Not reported

TABLE 2-2
CONCENTRATIONS OF PCDDs AND PCDFs IN FLY ASH FROM MUNICIPAL WASTE INCINERATORS IN ng/g(ppb)
PAGE TWO

Constituent	Reference 23	Reference 64				
		Type 1	Type 2	Type 3	Range	Range
DCDD		4-32	11-200	0.4-5.2	0.4-200	
T_3CDD	--	1.2-5.1	1.1-82	1.3-2.8	1.1-82	
T_4CDD	8.6	10-48	7-250	32-36	7-250	2.4-85
PCDD	15.0	1.2-6.2	0.5-310	23-100	0.5-310	6.6-210
HCDD	13.0	0.2-0.9	0.2-6.7	3.7-110	0.2-110	9.7-350
H_7CDD	3.2	Tr-3.9	Tr 6.7	ND-410	ND-410	5.7-184
OCDD	0.4	ND 0.2	ND	ND-11	ND-11	2.1-35
2,3,7,8-TCDD		0.2-8.0	0.1-7.9	1.0-2.4	0.1-8.0	
Total PCDD		**22-89**	**20-870**	**71-560**	**20-870**	
DCDF		1.7-21	4-20	ND-3.9	ND-21	
T_3CDF		0.7-4.5	1.8-32	6.2-9.0	0.7-32	
T_4CDF		0.4-8.9	0.9-31	1.0-9.9	0.4-31	4.4-210
PCDF		ND-73	12-180	2.4-24	ND-180	18-550
HCDF		Tr-1.9	0.2-42	Tr-56	Tr-56	22-1,100
H_7CDF		0.4-0.7	Tr-10	0.2-11	Tr-11	11-500
OCDF		ND-0.5	ND-0.2	0.4-23	ND-23	0.7-24
2,3,7,8-TCDF		0.5-1.4	0.2-5.4	0.1-2.4	0.1-5.4	
Total PCDF		**4.5-110**	**19-310**	**36-120**	**4.5-310**	
No. of Samples	Represents Average of 5 replicates	3 Incinerators	2 Incinerators	3 Incinerators	8 Incinerators	Not given
Sample Taken	ESP	Wet Scrubber	ESP	Wet Scrubber and ESP	Combination Wet Scrubber and ESP	Not given
Country	Canada	Japan	Japan	Japan	Japan	N. America

*Includes total of both PCDD and PCDF
Tr = 0.001 < Tr < 0.1 ng/g (ppb)
ND = Below detection limit

ESP = Electrostatic precipitator
Blank = Not reported

TABLE 2-2
CONCENTRATIONS OF PCDDs AND PCDFs IN FLY ASH FROM MUNICIPAL WASTE INCINERATORS IN ng/g (ppb)
PAGE THREE

Constituent	Reference 30	Reference 13	Reference 12 Average Particle Size (μm)*						
			30	80	125	200	550	>850 (light ash)	>850 (agglomerate particles)
Weight Fraction			0.37	0.27	0.09	0.08	0.14	0.02	0.02
MCDD	2.0								
DCDD	22								
T$_3$CDD	55								
T$_4$CDD	170	15-68	2.2-2.9	2.0-4.3	3.9-7.5	7.0-8.2	12-15	7.3-8.4	2.0-4.3
PCDD	530	17-73	3	2-5	4-9	8	10	4-5	2-6
HCDD	52	13-46	3	3-4	6	5-10	4-8	1-2	2-5
H$_7$CDD	7.4	3-13	2-3	1-3	2-4	1-6	1-3	0.1-0.3	2-3
OCDD	2.6	4-31	5-9.5	2.9-4.5	4.8-6.9	2-8.2	0.7-3.1	0.2	8.2-11
2,3,7,8-TCDD	2.1								
Total PCDD	**800**	**57-220**	**20**	**10-20**	**30**	**20-40**	**30-40**	**10-20**	**20-30**
MCDF	41								
DCDF	90								
T$_3$CDF	550								
T$_4$CDF	410								
PCDF	1,800								
HCDF	83								
H$_7$CDF	9.5								
OCDF	1.4								
2,3,7,8-TCDF									
Total PCDF	**3,000**								
No. of Samples	2 Composites	8	2						
Sample Taken	ESP	ESP	ESP						
Country	USA	Ontario, Canada	Canada						

*Concentration is reported in μg/g (ppb) of each particle size fraction.

ESP = Electrostatic precipitator

Blank = Not reported

TABLE 2-2
CONCENTRATIONS OF PCDDs AND PCDFs IN FLY ASH FROM MUNICIPAL WASTE INCINERATORS IN ng/g (ppb)
PAGE FOUR

Constituent	Reference 63	Reference 26			Reference 62		
T_4CDD	2.3-43						
PCDD	11-722						
HCDD	18-5,565						
H_7CDD	14-3,030						
OCDD	11-3,152						
2,3,7,8-TCDD	0.11 - 3.9	42					
Total PCDD	**64.3-10,883**	**1,600**	**23**	**78**	**5.23 - 17.7**	**40.2 - 272**	**124 - 629**
T_4CDF	20-169						
PCDF	7.1-226						
HCDF	14-2,353						
H_7CDF	3.8-666						
OCDD	1.4-362						
2,3,7,8-TCDF							
Total PCDF	**60.2-3,187**	**1,100**	**46**	**13**	**3.73 - 12.2**	**28.6 - 143**	**128 - 373**
No. of Samples	20 Samples from 4 Incinerators	Not given	Not given	Not given	6	4	6
Sample Taken	ESP or Cyclone Separator Conveyors	Not given	Not given	Not given	Wet/Dry Scrubber	Dry Scrubber	Fabric filter dust collector
Country	USA	Philadelphia, PA, USA	Ontario, Canada	Prince Edward Island, Canada	Quebec, Canada	Quebec, Canada	Quebec, Canada

ESP = Electrostatic precipitator
Blank = Not reported

TABLE 2-3

CONCENTRATIONS OF PCBs IN FLY ASH FROM MUNICIPAL INCINERATORS IN ng/g (ppb)

Constituent	Reference 30	Reference 63	Reference 26		Reference 64				Reference 62		
					Type 1	Type 2	Type 3	Range			
Monochlorobiphenyl	9.5	0.29 - 1.46									
Dichlorobiphenyl	9.9	0.13 - 7.87			Tr	0.9 - 2.1	Tr - 0.9	Tr - 2.1			
Trichlorobiphenyl	11	0.52 - 7.67			4.1 - 25	18 - 18	ND - 5.3	ND - 25			
Tetrachlorobiphenyl	3.8	1.02 - 5.52			1.2 - 42	22 - 27	0.5 - 5.1	0.5 - 42			
Pentachlorobiphenyl	5.1	0.87 - 225			1.5 - 130	10 - 12	2.4 - 18	1.5 - 130			
Hexachlorobiphenyl	0.45				0.9 - 55	29 - 65	1.2 - 12	0.9 - 65			
Heptachlorobiphenyl	0.1				ND	ND	ND	ND			
Octachlorobiphenyl	1.2				ND	ND	ND	ND			
Nonachlorobiphenyl	ND										
Decachlorobiphenyl	ND										
Total chlorobiphenyl	4.1	ND - 24.77	1.4	4	12 - 250	63 - 82	9.8 - 28	9.8-250	0.21 - 0.71	0.44 - 2.64	1.57 - 31.8
No of Samples	2 composites	23 samples from 4 Incinerators	Not Given	Not Given	3 Incinerators	2 Incinerators	3 Incinerators	8 Incinerators	6	4	6
Sample Taken									Wet/Dry Scrubber	Dry Scrubber	Fabric Filter Dust Collector
Country	USA	USA	Ontario, Canada	Prince Edward Island, Canada	Japan				Ontario, Canada Wet/Dry Scrubber	Ontario, Canada Dry Scrubber	Ontario, Canada Fabric Filter Dust Collector

ND = Below detection limit
Tr = Trace: 0.01 ng/g (ppb) < Tr < 0.1 ng/g (ppb)

- PCDDs, PCDFs, and PCBs are found in MSW incinerator fly ash in varied concentrations.

- The ranges of PCDD, PCDF, and PCB concentrations are quite wide, covering several orders of magnitude. These wide ranges of concentrations may be attributed to the following phenomena:

    - Differences in sampling, extraction, and analytical techniques employed, and in the inaccuracies inherent to comparing results at levels of ng/g (ppb) obtained via such different techniques.

    - Varied degrees of QA/QC employed during sampling and analysis.

    - Wide variability in MSW characteristics from incinerator to incinerator.

    - Different design and operating characteristics of the sampled MSW incinerators.

    - Varied objectives of the studies. For example, one study objective may be the characterization of ash while another may be a certain extraction procedure to determine the performance of chemicals.

- The highest concentrations of PCDDs and PCDFs were measured in fly ashes from MSW incinerators in the USA. However, the highest concentrations of PCBs (except Hexa CB) were found in fly ashes from Japanese MSW incinerators.

- Several studies(12,62) indicate higher PCDD and PCDF concentrations on smaller particles. This circumstance may be the result of the smaller particles' having larger surface areas. This may imply that PCDD and PCDF concentrations in fly-ash particles from fabric filter dust collectors (baghouses) would be higher than those found on fly-ash particles from electrostatic precipitators and scrubbers (wet, wet/dry, and dry). Moreover, the data also imply that these compounds have more affinity for smaller particles than for larger particles.

2.1.2 Organic Concentrations

Ranges of concentrations of organics such as PAHs, phthalates, chlorinated benzenes, and chlorinated phenols (CP) in fly ash from MSW incinerators are presented in Table 2-4. Detailed concentrations for each pertinent reference are presented in Table 2-5. The following are salient features of the data presented in these two tables.

- Organics such as polynuclear aromatic hydrocarbons (PAHs), phthalates, chlorinated benzenes, chlorinated phenols (CPs), and naphthalenes are found in fly ash from MSW incinerators in varied concentrations.

- In most cases, the ranges of these concentrations of organics are very wide and cover several orders of magnitudes. The possible reasons for these wide ranges have been delineated in Section 2.1.1.

- Examples of high concentrations of organics in fly ash are 9,300 ng/g (ppb) for naphthalene; 5,640 ng/g (ppb) for total PAH; 4,220 ng/g (ppb) for chlorinated benzene; and 9,630 ng/g (ppb) for CP.

- Highest concentrations of these organics were measured in fly ashes in North American (USA and Canada) MSW incinerators.

TABLE 2-4

RANGES OF CONCENTRATIONS OF ORGANICS IN FLY ASH FROM MUNICIPAL WASTE INCINERATORS IN ng/g (ppb)

Constituent	Concentration	References
Naphthalene	270-9,300	26, 30
Biphenyl	2-1,300	12, 13, 22
Acenaphthylene	ND-3,500	13, 22, 26, 30
Anthracene	1-500	12, 21, 22, 26
Fluorene	ND-100	12, 13, 21, 22, 26, 30
Phenanthrene	21-7,600	26, 30
Di-n-butyl phthalate	ND	30
Fluoranthene	ND-6,500	12, 13, 21, 22, 26, 30
Pyrene	ND-5,400	12, 13, 21, 22, 26, 30
Butyl benzyl phthalate	ND	30
Chrysene	ND-690	26,30
Bis(2-ethylhexyl)phthalate	85	30
Benzanthrene	ND-300	21
Benzo(k)fluoranthene	ND-470	21, 22, 30
Benzo(a)pyrene	ND-400	21, 22, 26, 30
Benzo(g,h,i)perylene	ND-190	26, 30
Diethyl phthalate	6,300	12
Normal alkanes	50,000	12
Chlorobenzenes	80-4,220	26, 62
Chlorophenols	50.1-9,630	26, 62
Total PAH	8-5,640	13, 22, 62
Country		USA, Canada, The Netherlands, Japan

ND = Below detection limit

TABLE 2-5

CONCENTRATIONS OF ORGANICS IN FLY ASH FROM MUNICIPAL WASTE INCINERATORS IN ng/g (ppb)

Constituent	Reference 30	Reference 22	Reference 21			Reference 13
Naphthalene	9300					
Biphenyl		2 - 350				18 - 110
Acenaphthylene	3500	ND - 28				31 - 200
Anthracene		4 - 380	10 - 500	200	10	
Fluorene	34	<0.5 - 64	0 - 10	60	0	1 - 49
Phenanthrene	7600					
Di-n-butyl phthalate	ND					
Fluoranthene	6500	0.5 - 440	2 - 500	20	0 - 3	5 - 68
Pyrene	5400	0.5 - 120	1 - 500	10	0 - 1	1 - 44
Butylbenzyl phthalate	ND					
Chrysene	690					
Bis(2-ethylhexyl) phthalate	85					
Benzanthrene			0 - 300	0	4 - 10	
Benzo(k)fluoranthene	470	ND - 23	0 - 400	0	0	
Benzo(a)pyrene	320	ND - 14	0 - 400	0	0	
Benzo(g,h,i)perylene	190					
Chlorobenzenes						
Chlorophenols						
Total PAH		8 - 1300				56 - 490
No. of samples	2 composites	8	2	1	2	8
Country	USA	Canada	Canada	The Netherlands	Japan	Canada

ND = Below detection limit

TABLE 2-5
CONCENTRATIONS OF ORGANICS IN FLY ASH FROM MUNICIPAL WASTE INCINERATORS IN ng/g (ppb)
PAGE TWO

Constituent	Reference 26	Reference 62		
Naphthalene	270			
Biphenyl				
Acenaphthylene	0			
Anthracene	1			
Fluorene	4			
Phenanthrene	21			
Di-n-butyl phthalate				
Fluoranthene	3			
Pyrene	3			
Butylbenzyl phthalate				
Chrysene	0			
Bis(2-ethylhexyl) phthalate				
Benzanthrene				
Benzo(k)fluoranthene				
Benzo(a)pyrene	0			
Benzo(g,h,i)perylene	0			
Chlorobenzenes	220	80 - 280	597 - 983	1,890 - 4,220
Chlorophenols	520	50.1 - 496	617 - 1,380	2,550 - 9,630
Total PAH		33.1 - 771	65.3 - 780	292 - 5,640
No. of samples	Not given	6	4	6
Country	Prince Edward Island, Canada	Ontario, Canada Wet/Dry Scrubber	Ontario, Canada, Dry Scrubber	Ontario, Canada Fabric filter Dust Collector

TABLE 2-5
CONCENTRATIONS OF ORGANICS IN
FLY ASH FROM MUNICIPAL WASTE INCINERATORS IN ng/g (ppb)
PAGE THREE

Constituent	Reference 12 Average Particle Size (µm)							
	30	80	125	200	550	>850 (light ash)	>850 (Agglomerate particles)	Total
Diethyl phthalate	240	95	150	650	1200	3200	750	6300
Dibutyl phthalate	690	510	510	680	910	2800	330	6400
Biphenyl	43	35	33	160	240	700	55	1300
Fluorene	24	3.8	3.5	-	69	-	-	100
Anthracene	16	4.0	2.9	2.9	-	-	-	26
Fluoranthene	74	51	68	97	120	150	7.9	570
Pyrene	44	16	13	18	9.1	-	-	100
Normal alkanes	14,000	7900	5200	5400	11,000	5500	900	50,000
Total	15,000	8600	5900	7000	14,000	12,000	2000	65,000
No. of samples	2							
Country	Canada							

2.1.3 Inorganic Constituent Concentrations

Ranges of concentrations of inorganic constituents in fly ash from MSW incinerators are presented in Table 2-6. Detailed concentrations for each pertinent reference are presented in Table 2-7. Salient features of the data presented in these tables are listed below:

- Inorganic constituents, including heavy metals, are found in MSW incinerators fly ash in varied concentrations.
- The ranges of concentrations are quite wide, covering, for some of the constituents, several orders of magnitude. The reasons for the wide variability are the same as those discussed in Section 2.1.1.
- Ranges of concentrations of several of the constituents regulated under RCRA are 15 to 750 µg/g (ppm) for arsenic, <5 to 2,210 µg/g (ppm) for cadmium, 21 to 1,900 µg/g (ppm) for chromium, 200 to 26,600 µg/g (ppm) for lead, and 0.9 to 35 µg/g (ppm) for mercury.
- The larger concentrations of inorganic constituents are found on the smaller size particulate matter. These data indicate that the inorganic constituents seem to concentrate on the smaller particles. The more volatile metals move through the incinerator until the temperature or the pollution control devices employed by the incinerator condense these metals out. The smaller particle size means an increase in surface area available for adsorption. The smaller mass of the smaller particulates also means smaller mass available for dilution.

TABLE 2-6

RANGES OF CONCENTRATIONS OF INORGANIC CONSTITUENTS IN FLY ASH FROM MUNIICPAL WASTE INCINERATORS IN µg/g (ppm)

Constituent	Concentration	References
Arsenic	15-750	26, 29, 36, 45, 63
Barium	88-9,000	8, 26, 29, 36, 40, 45
Cadmium	<5-2,210	6, 26,29, 36, 40, 45, 62, 63
Chromium	21-1,900	6, 8, 26, 29, 36, 40, 45, 62, 63
Lead	200-26,600	6, 8, 26, 36, 40, 45, 62, 63
Mercury	0.9-35	6, 26, 40, 45, 63
Selenium	0.48-15.6	26, 29, 40, 45, 63
Silver	ND-700	8, 26, 29, 40, 45
Aluminum	5,300-176,000	8, 26, 29, 40, 45
Antimony	139-760	26, 29, 40
Beryllium	<4	26, 36, 45
Bismuth	36-<100	26
Boron	35-5,654	26, 45, 62
Bromine	21-250	29
Calcium	13,960-270,000	8, 26, 29, 40, 45
Cesium	2,100-12,000	29
Cobalt	2.3-1,670	6, 26, 29, 40, 45, 62
Copper	187-2,380	6, 8, 26, 29, 40, 45, 62, 63
Iron	900-87,000	8, 26, 29, 36, 40, 45, 63
Lithium	7.9-34	26, 40, 45
Magnesium	2,150-21,000	8, 26, 29, 40, 45
Manganese	171-8,500	8, 26, 29, 40, 45, 63
Molybdenum	9.2-700	26, 45
Nickel	9.9-1,966	6, 8, 26, 29, 36, 40, 45, 62, 63
Phosphorus	1,770-9,300	8, 26
Potassium	11,000-65,800	8, 26, 40, 45
Silicon	1,783-266,000	8, 26
Sodium	9, 780-49,500	8, 26, 29, 40, 45
Strontium	98-1100	26, 29, 36, 45
Tin	300-12,500	8, 26, 29, 40, 45
Titanium	<50-42,000	8, 26, 29, 45
Vanadium	22-166	26, 29, 45
Yttrium	2-380	45

TABLE 2-6
RANGES OF CONCENTRATIONS OF INORGANIC CONSTITUENTS IN FLY ASH FROM MUNICIPAL WASTE INCINERATORS IN µg/g (ppm)
PAGE TWO

Constituent	Concentration	References
Zinc	2,800-152,000	6, 8, 26, 29, 36, 40, 45, 62, 63
Gold	0.16-100	8, 29
Chloride	1,160-11,200	29
Sulfate	3,200-32,800 (sulfur)	29
Country		USA, Canada

TABLE 2-7

CONCENTRATIONS OF INORGANIC CONSTITUENTS IN FLY ASH FROM MUNICIPAL WASTE INCINERATORS IN μg/g (ppm)

Constituent	Reference 36	Reference 61							Reference 29	Reference 29	Reference 40
		0.37 μm	0.65 μm	1.5 μm	2.4	6 μm	15 μm	30 μm			
Arsenic	15 - 750	712	1,619	1,435	1,250	915	565	321	9.4 - 74	55 -65	
Barium	190 - 870	252	988	880	1,000	789	334	<405	1,600 - 3,600	3,200	1,500
Cadmium	94 - 2,210			<631	<167	416	<92		<5 - 125	180 - 194	64
Chromium	59 - 200				70				1,070 - 1,900	730 - 820	1,160
Lead	2,300 - 26,600				500						7,200
Mercury											0.9
Selenium		<6	45	41	62	64	166	177	1.4 - 11	11 - 13	
Silver									52 - 140	210 - 220	130
Aluminum					46,400				9,000 - 142,000	131,000-138,000	121,000
Antimony		103	30	30	17	31	24	22	139 - 760	570 - 600	340
Beryllium	< 0.28 - 1.0										
Bismuth											
Boron											
Bromine		85	140	95	70	57	150	546	61 - 250	21 - 54	
Calcium		<56,000	30,000	17,000	21,000	20,000	<41,000	<33,000	33,000 - 86,000	49,000 - 52,000	23,000
Cesium									2,100 - 12,000	8,300 - 11,800	
Cobalt		81	90	59	10	79	32	24	26 - 54	25 - 29	100
Copper					100				300 - 2,000	800 - 1,200	510
Iron	5,600 - 33,100	89,000	28,000	28,000	45,000	39,000	119,000	127,000	34,000 - 87,000	24,000 - 26,000	24,000

TABLE 2-7
CONCENTRATIONS OF INORGANIC CONSTITUENTS
IN FLY ASH FROM MUNICIPAL WASTE INCINERATORS IN µg/g (ppm)
PAGE TWO

Constituent	Reference 36	Reference 61							Reference 29	Reference 29	Reference 40
		0.37 µm	0.65 µm	1.5 µm	2.4	6 µm	15 µm	30 µm			
Lithium											34
Magnesium					4,060				5,000 - 21,000	10,000 - 15,000	9,700
Manganese		79	167	183	190	206	666	947	2,700 - 8,500	2,000 - 2,300	1,500
Molybdenum					<20						
Nickel	29 - 270				1,000				580 - 960		1,800
Phosphorus					1,770						
Potassium		5,400	11,800	11,500	11,600	1,000	3,000	2,500			12,200
Silicon											
Sodium		1,720	2,250	2,000	2,930	2,680	1,470	1,900	11,200 - 19,400	14,300 - 14,900	16,000
Strontium	98 - 290	420	1,030	640	1,090	910	<330	<161	260 - 1,100	220 - 350	
Tin									1,180 - 1,740	2,300 - 2,600	1,250
Titanium									26,000 - 42,000	25,000 - 32,000	
Vanadium					800				110 - 166	129 - 146	
Yttrium		<1	4	3	4	4	4	<2			
Zinc	3,650 - 152,000	600	830	530	<560	410	1,420	24,300	7,800 - 13,600	23,000 - 26,000	10,000
Gold									0.16 - 3.7	0.48 - 0.69	
Chloride									3,000 - 11,200	1,160 - 1,530	
Sulfate											
No. of Samples	5 from 5 incinerators	2 samples composite							33	3	Not given
Pollution Control	Wet scrubbers, baghouse & ESP	Not given (power plant that burns refuse derived fuel)							Spray baffle scrubber	Mechanical separator & ESP	Spray baffle scrubber
Country	USA	USA							Alexandria, VA, USA	Washington, D C, USA	USA

TABLE 2-7
CONCENTRATIONS OF INORGANIC CONSTITUENTS IN FLY ASH FROM MUNICIPAL WASTE INCINERATORS IN µg/g (ppm)
PAGE THREE

Constituent	Reference 8	Reference 6	Reference 63	Reference 62	Reference 62	Reference 62
Arsenic			16-149			
Barium	900 - 2,300					
Cadmium		791	107 - 475	23 - 45	26 - 145	233 - 354
Chromium	500 - 1,100	399	48 - 105	530 - 1,071	653 - 1,068	193 - 992
Lead	2,500 - 18,400	24,400	2,830 - 14,400	1,749 - 2,286	3,250 - 4,762	5,770 - 8,297
Mercury		1.24	0.44 - 35			
Selenium			2.5 - 15.6			
Silver	100 - 700					
Aluminum	86,800 - 138,500					
Antimony						
Beryllium						
Bismuth						
Bromine						
Boron				70 - 2,270	474 - 2,362	90 - 5,654
Calcium	41,600 - 79,200					
Cesium						
Cobalt		9		90 - 1,670	66 - 350	<25 - 141
Copper	500 - 1,400	467	484 - 2,380	499 - 738	622 - 721	412 - 623
Iron	14,000 - 45,200		5,960 - 22,300			
Lithium						

TABLE 2-7
CONCENTRATIONS OF INORGANIC CONSTITUENTS
IN FLY ASH FROM MUNICIPAL WASTE INCINERATORS IN μg/g (ppm)
PAGE FOUR

Constituent	Reference 8	Reference 6	Reference 63	Reference 62	Reference 62	Reference 62
Magnesium	7,600 - 11,900					
Manganese	600 - 4,000		320 - 1,410			
Molybdenum						
Nickel	100 - 400	64	52 - 245	654 - 1,966	280 - 553	21 - 189
Potassium	11,200 - 19,200					
Phosphorus	2,900 - 7,600					
Sodium	10,900 - 23,300					
Silicon	128,400 - 228,800					
Strontium						
Tin	900 - 4,500					
Titanium	1,700 - 22,500					
Vanadium						
Yttrium						
Zinc	6,000 - 16,500	40,950	8,460 - 38,800	4,758 - 5,900	6,771 - 15,150	6,089 - 19,125
Gold	100					
Chloride						
Sulfate	3,200 - 31,800 (sulfur)					
No. of Samples	Not given	Not given	20 from 4 incinerators	6	4	6
Pollution Control	Not given	Not given	Machanical separators & ESP	Wet dry scrubber	Dry scrubber	Baghouse
Country	USA	Canada	USA	Canada	Canada	Canada

TABLE 2-7
CONCENTRATIONS OF INORGANIC CONSTITUENTS
IN FLY ASH FROM MUNICIPAL WASTE INCINERATORS IN µg/g (ppm)
PAGE FIVE

Constituent	Reference 26			Reference 45
Arsenic	41 - 77		154	4.8 - 59
Barium	1,400 - 2,500	3,000 - >9,000	88	97 - 9,000
Cadmium	45 - 64		683	42 - 470
Chromium	730 - 1,430	300 - 900	180	21 - 1,330
Lead	4,000 - 10,000	200 - 4,000	8,533	200 - 10,000
Mercury	0.88	<300	5	3.1 - 6.77
Selenium			10	0.48 - 0.50
Silver	95 - 130	<100 - >300	0	10 - 220
Aluminum	111,000 - 126,000	107,900 - 176,000	48,033	5,300 - 176,000
Antimony	260 - 340			
Beryllium	<4		0	0.10 - 0.60
Bismuth		<100	36	
Boron		<200	150	35 - 257
Bromine				
Calcium	22,000 - 40,000	39,000 - 52,000	70,167	13,960 - 270,000
Cesium				
Cobalt	30 - 100		41	2.3 - 100
Copper	445 - 1,000	600 - 900	415	187 - 2,305
Iron	22,000 - 46,000	20,000 - 30,200	12,100	900 - 52,000
Lithium	31 - 34			7.9 - 34

TABLE 2-7
CONCENTRATIONS OF INORGANIC CONSTITUENTS
IN FLY ASH FROM MUNICIPAL WASTE INCINERATORS IN $\mu g/g$ (ppm)
PAGE SIX

Constituent	Reference 26			Reference 45
Magnesium	9,500 - 12,000	9,800 - 10,600	8,950	2,150 - 14,400
Manganese	1,100 - 3,400	400 - <900	2,160	171 - 4,300
Molybdenum		<200 - 700	58	9.2 - 100
Nickel	160 - 1,800	<100 - <300	100	9.9 - 1,800
Phosphorus		6,400 - 9,300	4,600	
Potassium	12,200 - 14,000	11,000 - 15,800	58,167	6400-65,800
Silicon		184,500 - 266,000	1,783	
Sodium	14,000 - 16,700	13,600 - 26,800	49,500	9,780 - 26,800
Strontium	210 - 260			208 - 610
Tin	850 - 1,250	300 - 600	834	300 - 12,500
Titanium	<50	21,900 - 34,100	4,167	664 - 34,100
Vanadium			61	22 - 140
Yttrium				2 - 380
Zinc	8,000 - 10,100	2,800 - 9,000	32,400	2,800 - 24,600
Gold				
Chloride				
Sulfate				
No. of Samples	Not given	5	Not given	2-16 depending on constituent
Pollution Control	Spray baffle scrubber	Not given	Not given	Not given
Country	Alexandria, VA, USA	Not given	Prince Edward Island	Ogden Projects, USA

2.2 BOTTOM ASH

2.2.1 PCDD, PCDF, and PCB Concentrations

Ranges of concentrations of PCDDs, PCDFs, and PCBs in bottom ash from MSW incinerators are presented in Table 2-8. Detailed concentrations for each pertinent reference are presented in Tables 2-9 and 2-10. The salient features of the data presented in these tables are as follows:

- PCDDs, PCDFs, and PCBs are found in MSW incinerator bottom ash in varied concentrations.
- In most cases, the ranges of PCDD, PCDF, and PCB concentrations are very wide and cover several orders of magnitude for the same reasons discussed in Section 2.1.1.
- Concentrations of 2,3,7,8-TCDD in bottom ash samples range from 0.03 to 0.7 ng/g (ppb). Total PCDD and PCDF concentration ranges are 0 to 110 ng/g (ppb) and 0 to 65 ng/g (ppb), respectively. PCB concentrations range from 0 to 180 ng/g (ppb) in bottom ash.
- Overall PCDD, PCDF, and PCB concentrations in bottom ash are much lower than those found in fly ash, a fact which points again to the concentrating effect of these constituents on smaller particles.
- U.S. studies indicate very low concentrations of PCBs in bottom ashes from U.S. incinerators compared to concentrations of PCBs in bottom ashes from Japanese incinerators. This is consistent with the occurrence of higher concentrations of PCBs in fly ash samples collected from Japanese incinerators as compared to U.S. incinerators..
- The data base for the concentrations of these constituents in bottom ash is much smaller than the data base for fly ash, a fact which indicates the expectations for low concentrations in bottom ash.

TABLE 2-8

RANGES OF CONCENTRATIONS OF PCDDS, PCDFS, AND PCBs IN BOTTOM ASH FROM MUNICIPAL WASTE INCINERATORS IN ng/g (ppb)

Constituent	Concentration	References
MCDD	ND	30
DCDD	ND	30
T_3CDD	ND	30
T_4CDD	<0.04-0.65	30, 63
PCDD	ND-3	30, 63
HCDD	ND-2.3	30, 63
H_7CDD	ND-6.3	30, 63
OCDD	ND-29	30, 63
2,3,7,8-TCDD	<0.04-0.7	26, 63
Total PCDD	0-110	26, 30, 63
MCDF	1.1	30
DCDF	0.63	30
T_3CDF	ND	30
T_4CDF	0.15-1.4	30, 63
PCDF	0.07-6.2	30, 63
HCDF	ND-2.5	30, 63
H_7CDF	ND-6.9	30, 63
OCDF	ND-3.7	30, 63
2,3,7,8-TCDF	0.10	63
Total PCDF	ND-65	26, 30, 63
Mono CB	ND-1.3	30, 63
Di CB	ND-5.5	30, 63, 64
Tri CB	ND-80	30, 63, 64
Tetra CB	ND-47	30, 63, 64
Penta CB	ND-48	30, 64
Hexa CB	ND-39	30, 64
Hepta CB	ND	30, 64
Octa CB	ND	30, 64
Nona CB	ND	30
Deca CB	ND	30
Total PCB	ND-180	26, 30, 63, 64
Country		USA, Canada, Japan

ND = Below Detection Limit
CB = Chlorobiphenyl

TABLE 2-9

CONCENTRATIONS OF PCDDs AND PCDFs IN BOTTOM ASH FROM MUNICIPAL WASTE INCINERATORS IN ng/g (ppb)

Constituent	Reference 30	Reference 26			Reference 63
MCDD	ND				
DCDD	ND				
T_3CDD	ND				
T_4CDD	0.32				<0.04-0.65
PCDD	ND				<0.01-2
HCDD	ND				0.02-2.3
H_7CDD	ND				0.09-6.3
OCDD	ND				0.16-29
2,3,7,8-TCDD		0.7			<0.04-0.01
Total PCDD	**0.32**	**110**	**0.5**	**ND**	0.27-40.25
MCDF	1.1				
DCDF	0.63				
T_3CDF	ND				
T_4CDF	1.4				0.15-1.3
PCDF	6.2				0.07-1.5
HCDF	ND				0.02-2.5
H_7CDF	ND				0.04-6.9
OCDF	ND				<0.04-3.7
2,3,7,8-TCDF					0.03-0.3
Total PCDF	**9.3**	**65**	**0.6**	**ND**	0.28-15.9
No. of Samples	2 Composites	Not given	Not given	Not given	5 from 1 incinerator
Country	USA	Philadelphia, PA, USA	Ontario, Canada	Prince Edward Island, Canada	USA

ND = Below detection limit
Blank = Not reported

TABLE 2-10

CONCENTRATIONS OF PCBs IN BOTTOM ASH FROM MUNICIPAL WASTE INCINERATORS IN ng/g (ppb)

Constituent	Reference 30	Reference 63	Reference 26		Reference 64			
					Type 1	Type 2	Type 3	Range
Monochlorobiphenyl	1.3	ND						
Dichlorobiphenyl	ND	ND			Tr	Tr - 5.5	Tr	Tr - 5.5
Trichlorobiphenyl	0.12	ND			0.2 - 13	1.5 - 80	0.1 - 3.7	0.1 - 80
Tetrachlorobiphenyl	ND	ND			0.7 - 13	0.9 - 47	0.1 - 22	0.1 - 47
Pentachlorobiphenyl	ND	ND			0.4 - 13	0.3 - 10	0.2 - 48	0.2 - 48
Hexachlorobiphenyl	ND				0.1 - 20	2.6 - 39	ND - 25	ND - 39
Heptachlorobiphenyl	ND				ND	ND	ND	ND
Octachlorobiphenyl	ND				ND	ND	ND	ND
Nonachlorobiphenyl	ND							
Decachlorobiphenyl	ND							
Total chlorobiphenyl	1.5	ND	0.4	ND	1.4 - 58	5.2 - 180	0.4 - 97	0.4-180
No. of Samples	2 composites	5 from 1 Incinerator	Not Given	Not Given	3 Incinerators	2 Incinerators	3 Incinerators	8 Incinerators
Country	USA	USA	Ontario, Canada	Prince Edward Island, Canada	Japan			

ND = Below detection limit
Tr = Trace: 0.01 ng/g (ppb) < Tr < 0.1 ng/g (ppb)
Blank = Not reported

2.2.2 Organic Concentrations

Ranges of concentrations of organics such as polyaromatic hydrocarbons, phthalates, chlorinated benzenes, and chlorinated phenols in bottom ash from MSW incinerators are presented in Table 2-11. Detailed concentrations for each pertinent reference are presented in Table 2-12. The salient features of the data listed in these tables are basically the same as those outlined in Section 2.2.1 with one exception: semi-volatile compounds seem to be in bottom ash at higher levels than in fly ash.

2.2.3 Inorganic Constituent Concentrations

Ranges of concentrations of inorganic constituents in bottom ash from MSW incinerators are presented in Table 2-13. Detailed concentrations for each pertinent reference are presented in Table 2-14. Salient features of the data given in these tables are as follows:

- Inorganic constituents, including heavy metals, are found in MSW incinerator bottom ash in varied concentrations.

- The ranges of concentrations are quite wide, covering, for some of the constituents, several orders of magnitude. The reasons for the wide range of variability are discussed in Section 2.1.1.

- Concentrations of several of the constituents regulated under RCRA range from 13 to 520 µg/g (ppm) for chromium, 110 to 5,000 µg/g (ppm) for lead, and 1.1 to 46 µg/g (ppm) for cadmium.

- Overall concentrations of inorganic constituents in bottom ash are smaller than those found in fly ash. This fact again indicates the concentrating effect of these contaminants on the smaller particles of the fly ash.

- The data base for bottom-ash inorganic constituents is smaller than the data base for fly-ash inorganic constituents for the same reasons indicated in Section 2.2.1. The data available are only from studies conducted in North America (United States and Canada).

TABLE 2-11

RANGES OF CONCENTRATIONS OF ORGANICS IN BOTTOM ASH FROM MUNICIPAL WASTE INCINERATORS IN ng/g (ppb)

Constituent	Concentration	References
Naphthalene	570-580	26, 30
Acenaphthylene	37-390	26, 30
Anthracene	53	26
Fluorene	ND-150	26, 30
Phenanthrene	500-540	26, 30
Di-n-butyl phthalate	360	30
Fluoranthene	110-230	26, 30
Pyrene	150-220	26, 30
Butyl benzyl phthalate	180	30
Chrysene	ND-37	26, 30
Bis(2-ethylhexyl)phthalate	2,100	30
Benzo(k)fluoranthene	ND-51	26, 30
Benzo(a)pyrene	ND-5	26, 30
Benzo(g,h,i)perylene	ND	30
Acenaphthene	28	26
Chlorobenzenes	17	26
Chlorophenols	ND	26
Total PAH	2 composite	26, 30
Country		USA, Canada

ND = Below detection limit

TABLE 2-12

CONCENTRATIONS OF ORGANICS IN BOTTOM ASH FROM MUNICIPAL WASTE INCINERATORS IN ng/g (ppb)

Constituent	Reference 30	Reference 26
Naphthalene	570	580
Acenaphthylene	390	37
Fluorene	ND	150
Phenathrene	500	540
Di-n-butyl phthalate	360	
Fluoranthene	230	110
Pyrene	220	150
Butyl benzyl phthalate	180	
Chrysene	ND	37
Bis(2-ethylhexyl)phthalate	2,100	
Benzo(k)fluoranthene	ND	51
Benzo(a)pyrene	ND	5
Benzo(g,h,i)perylene	ND	
Anthracene		53
Acenaphthene		28
Chlorobenzenes		17
Chlorophenols		0
No. of Samples	2 Composite	Not given
Country	USA	Prince Edward Island, Canada

ND = Below detection limit
Blank = Not reported

TABLE 2-13

RANGES OF CONCENTRATIONS OF INORGANIC CONSTITUENTS IN BOTTOM ASH FROM MUNICIPAL WASTE INCINERATORS IN µg/g (ppm)

Constituent	Concentration	References
Arsenic	1.3-24.6	26, 36, 63
Barium	47-2,000	26, 36, 40
Cadmium	1.1-46	6, 26, 36, 40, 63
Chromium	13-520	6, 26, 36, 40, 63
Lead	110-5,000	6, 26, 36, 40, 63
Mercury	ND-1.9	6, 26, 40, 63
Selenium	ND-2.5	26, 63
Silver	ND-38	26, 40
Aluminum	5,400-53,400	26, 40
Beryllium	ND-<0.44	26, 36
Bismuth	ND	26
Boron	85	26
Calcium	5,900-69,500	26, 40
Cobalt	3-62	6, 26, 40
Copper	80-10,700	6, 26, 40, 63
Iron	1,000-133,500	26, 36, 40, 63
Lithium	7-19	40
Magnesium	880-10,100	26, 40
Manganese	50-3,100	26, 40, 63
Molybdenum	29	26
Nickel	9-226	6, 26, 36, 40, 63
Phosphorus	3,400-17,800	26, 36
Potassium	920-13,133	26, 40
Silicon	1,333-188,300	26
Sodium	1,800-33,300	26, 40
Strontium	81-240	36
Tin	40-800	26, 40
Titanium	3,067-11,400	26
Vanadium	53	26
Zinc	200-12,400	6, 26, 36, 40, 63
Country		USA, Canada

TABLE 2-14

CONCENTRATIONS OF INORGANIC CONSTITUENTS IN BOTTOM ASH FROM MUNICIPAL WASTE INCINERATORS IN μg/g (ppm)

Constituent	Reference 36	Reference 40	Reference 40	Reference 6	Reference 63	Reference 26		
Arsenic	1.3 - 11				2.2 - 24.6			7
Barium	200 - 700	47 - 450	1,400			2,000 - 2,000		367
Cadmium	1.9 - 4.4	2 - 22	41	46	1.1 - 43			24
Chromium	13 - 50	20 - 100	520	139	24 - 105	300 - 400	50	100
Lead	330-1080	110 - 1,500	1,700	4,300	1,380 - 3,930	500 - 5,000	310	2,635
Mercury		0.66 - 1.9	0.4	0.11	0.12 - 0.36	<300 - <300		0
Selenium					2.5 - 2.5			0
Silver		<3 - 7	38			<100 - <100		0
Aluminum		5,400 - 12,000	49,000			24,700 - 53,400	19,100	32,667
Beryllium	<0.25 - <0.44							0
Bismuth								0
Boron								85
Calcium		5,900 - 17,000	40,000			66,500 - 69,500		54,667
Cobalt		<3 - 5	70	62				13
Copper		80 - 900	450	2,200	581 - 10,700	1,300 - 3,300	1,400	304
Iron	3,700 - 24,800	1,000 - 3,500	16,000		12,000-115,000	35,100 - 133,500	17,000	52,000
Lithium		<2 - 7	19					
Magnesium		880 - 2,100	12,800			6,100 - 10,100		8,733

TABLE 2-14
CONCENTRATIONS OF INORGANIC CONSTITUENTS
IN BOTTOM ASH FROM MUNICIPAL WASTE INCINERATORS IN µg/g (ppm)
PAGE TWO

Constituent	Reference 36	Reference 40	Reference 40	Reference 6	Reference 63	Reference 26		
Manganese		50 - 240	3,100		430 - 1,520	>1,000 - >1,000		1,111
Molybdenum						<100 - <100		29
Nickel	19 - 58	9 - 90	210	226	17 - 90	<100 - <300		67
Phosphorus	3,400 - 17,800					8,500 - 10,300		5,447
Potassium		920 - 1,900	6,300			7,800 - 8,400		13,133
Silicon						141,100-188,300		1,333
Sodium		1,800 - 7,400	8,200			19,400 - 33,300		10,500
Strontium	81-240							
Tin		<20 - 40	400			700 - 800	110	316
Titanium						3,400 - 11,400		3,067
Vanadium								53
Yttrium								
Zinc	710 - 2,030	200 - 2,500	5,500	4,800	914 - 12,400	2,000 - 3,000	2,300	4,233
Chloride								
Sulfate								
No. of Samples	5 from 5 incinerators	Samples from 6 incinerators	Not given	Not given	5	2	Not given	Not given
Pollution Control	Wet scrubber, baghouse and ESP	Spray baffle scrubbers, ESP	Spray baffle scrubber	Not given	Mechanical separators and ESP	Not given	ESP	Not given
Country	USA	USA	USA	Canada	USA	Not given	Philadelphia, PA, USA	Prince Edward Island, Canada

2.3 COMBINED BOTTOM AND FLY ASH

2.3.1 PCDD, PCDF, and PCB Concentrations

Ranges of concentrations of PCDDs, PCDFs, and PCBs in combined ash (fly and bottom) from MSW incinerators are presented in Table 2-15. The following are the salient features of the data presented in Table 2-15:

- PCDDs, PCDFs, and PCBs are found in combined ash from MSW incinerators in varied concentrations.
- In most cases, the ranges of concentrations for these constituents are quite wide and cover several orders of magnitude for reasons discussed in Section 2.1.1.
- Overall concentrations of PCDDs, PCDFs, and PCBs in combined bottom ash are smaller than those in fly ash alone and are larger than those of bottom ash alone. This is a direct result of mixing fly ash and bottom ash.
- The data base for the concentrations of these constituents in combined ash consists of only one study, the Versar Study, which is given in its entirety in Volume V of this report. This data base is the most limited, compared to the data bases for fly ash and bottom ash. The only study that provided the data reported here was sponsored by EPA and was conducted to provide information for the Congress-mandated report.

2.3.2 Organic Concentrations

No data are available in the reviewed literature for organics other than those discussed in Section 2.3.1.

TABLE 2-15

RANGES OF CONCENTRATIONS OF PCDDs, PCDFs, AND PCBs IN COMBINED ASH FROM MUNICIPAL WASTE INCINERATORS IN ng/g (ppb)

Constituent	Concentration	References
TCDD	0.14-14	63
PCDD	1.9-50	63
HCDD	1.4-78	63
H_7CDD	1.4-120	63
OCDD	0.84-89	63
2,3,7,8-TCDD	0.02-0.78	63
Total PCDD	6.2-350	63
TCDF	2.3-91	63
PCDF	1.6-37	63
HCDF	1.2-35	63
H_7CDF	0.62-36	63
OCDF	0.18-8.4	63
2,3,7,8-TCDF	0.41-12	63
Total PCDF	6.14-153.9	63
Mono CB	ND	63
Di CB	0.126-1.35	63
Tri CB	0.35-14.3	63
Tetra CB	16.5-16.5	63
Penta CB	ND	63
Total PCB	0-32.15	63

CB = Chlorobiphenyl
ND = Below detection limit

2.3.3 Inorganic Constituent Concentrations

Ranges of concentrations of inorganic constituents in combined bottom and fly ash are presented in Table 2-16. Detailed concentrations for each pertinent reference are included in Table 2-17. Salient features of the data listed in these tables follow:

- Inorganic constituents, including heavy metals, are found in combined bottom ash from MSW incinerators in varied concentrations.
- The ranges of concentrations are quite wide, covering, for some of the constituents, several orders of magnitude. Reasons for this wide variability are discussed in Section 2.1.1.
- Concentrations of several of the constituents regulated under RCRA range from 2.9 to 50 µg/g (ppm) for arsenic, 0.18 to 100 µg/g (ppm) for cadmium, 12 to 1,500 µg/g (ppm) for chromium, 31 to 36, 600 µg/g (ppm) for lead, and 0.05 to 93.4 µg/g (ppm) for silver.
- Overall concentrations of inorganic constituents in combined bottom ash are smaller than those of fly ash and are larger than those of bottom ash. This is because of the dilution of the high inorganic concentrations in fly ash with the low concentrations found in bottom ash.
- The data base for inorganic levels in combined bottom ash is about the same size as the data base for bottom ash, and is smaller than that for fly ash. The data available for combined-bottom-ash inorganic levels are from studies conducted in the USA only.

TABLE 2-16

RANGES OF CONCENTRATIONS OF INORGANIC CONSTITUENTS IN COMBINED BOTTOM AND FLY ASH FROM MUNICIPAL WASTE INCINERATORS IN µg/g (ppm)

Constituent	Concentration	References
Arsenic	2.9-50	26, 45, 63
Barium	79-2,700	26, 45
Cadmium	0.18-100	26, 45, 63
Chromium	12-1,500	26, 45, 63
Lead	31-36,600	26, 45, 63
Mercury	0.05-17.5	45, 63
Selenium	0.10-50	26, 45, 63
Silver	0.05-93.4	45
Aluminum	5,000-60,000	26, 45
Antimony	<120-<260	26
Beryllium	0.1-2.4	26, 45
Boron	24-174	45
Calcium	4,100-85,000	26, 45
Cobalt	1.7-91	26, 45
Copper	40-5,900	26, 45, 63
Iron	690-133,500	26, 45, 63
Lithium	6.9-37	45
Magnesium	700-16,000	26, 45
Manganese	14-3,130	26, 45, 63
Molybdenum	2.4-290	26, 45
Nickel	13-12,910	26, 45, 63
Phosphorus	290-5,000	26
Potassium	290-12,000	26, 45
Sodium	1,100-33,300	26, 45
Strontium	12-640	26, 45
Tin	13-380	45
Titanium	1,000-28,000	26, 45
Vanadium	13-150	26, 45
Yttrium	0.55-8.3	45
Zinc	92-46,000	45, 63
Country		USA

TABLE 2-17

CONCENTRATIONS OF INORGANIC CONSTITUENTS IN COMBINED BOTTOM AND FLY ASH FROM MUNICIPAL INCINERATORS IN μg/g (ppm)

Constituent	Reference 63	Reference 26				Reference 45
Arsenic	2.9 - 22.8	< 1,200	<620	< 1,200	<560	0.8 - 50
Barium		1,600	810	1,600	1,000	79 - 2,700
Cadmium	7.8 - 45	< 17	<8.9	< 17	<8	0.18 - 100
Chromium	12 - 332	230	320	320	1,500	16.3 - 1,500
Lead	259 - 13,200	<470	<250	<470	<230	31 - 36,600
Mercury	0.11 - 8.7					0.05 - 17.5
Selenium	0.25 - 2.5	<780	<420	<780	<380	0.10 - 50
Silver		<33	<17	<33	< 16	0.05 - 93.4
Aluminum		53,000	60,000	54,000	45,000	5,000 - 60,000
Antimony			< 140	<260	< 120	
Beryllium		<2.4	< 1.3	<2.4	< 1	0.1 - 2.4
Boron						24 - 174
Calcium		85,000	79,000	68,000	42,000	4,100 - 85,000
Cobalt		<24	<19	<91	<11	1.7 - 91
Copper	193 - 5,900	550	2,000	650	1,700	40 - 3,400
Iron	2,100 - 95,100	86,000	58,000	36,000	63,000	690 - 133,500
Lithium						6.9 - 37
Magnesium		16,000	7,700	8,600	6,500	700 - 16,000
Manganese	110 - 3,130	1,200	1,600	1,000	1,100	14 - 3,100

TABLE 2-17
CONCENTRATIONS OF INORGANIC CONSTITUENTS
IN COMBINED BOTTOM AND FLY ASH
FROM MUNICIPAL INCINERATORS IN μg/g (ppm)
PAGE TWO

Constituent	Reference 63	Reference 26				Reference 45
Molybdenum		290	170	200	260	2.4 - 290
Nickel	13 - 556	<200	<110	<200	<96	6.9 - 12,910
Phosphorus		5,000	2,500	3,600	290	
Potassium		11,000	5,800	12,000	5,500	290 - 10,500
Sodium		18,000	9,600	18,000	7,700	1,100 - 33,300
Strontium		270	380	300	220	12 - 640
Tin						13 -380
Titanium		11,000	1,000	9,100	2,900	1,000 - 28,000
Vanadium		36	33	51	18	13 - 150
Yttrium						0.55 - 8.3
Zinc	545 - 46,000					92 - 6,684
Chloride						
Sulfate						
No. of Samples	15 from three incinerators	Not given	Not given	Not given	Not given	5 - 54
Pollution Control	Mechanical separators and ESP	ESP	Not given	ESP	Not given	Not given
Country	USA	Chicago, IL, USA	Summer, TN,, USA	Hampton, VA, USA	Auburn, ME, USA	Ogden Projects,USA

3.0 CHARACTERIZATION OF EXTRACTS

Simulated leachability studies of ash from MSW incinerators are important in providing some insight into the potential leachability of organic and inorganic constituents into environmental media including soil, groundwater, and surface water. Laboratory batch leachability studies utilize different methods for extracting constituents from the ash. The most commonly used are

- Deionized Water Extraction (DWE) test method (SW-924)
- Extract Procedure (EP) test method
- Toxic Characteristic Leaching Procedure (TCLP) test methods

Both the EP and TCLP test methods are required as a part of the determination of hazardousness under the Resource Conservation and Recovery Act (RCRA). The EP test is the currently required test method; the TCLP is currently only proposed as a test method.

This section addresses concentrations of organic and inorganic constituents in extracts obtained from laboratory leachability studies on fly, bottom, and combined ashes. It is based on information gathered from U.S. and Canadian studies. No leachability data from European or Japanese studies are available in the literature reviewed.

In contrast to the data available on ash characterization, data on extracts are more limited. Most of the data available address inorganic constituents, and very little data address organics. The RCRA requirements for the EP toxicity test include the analysis for regulated drinking-water-quality parameters only, including selected metals and pesticides. This is probably the main reason for the limited data base available.

3.1 FLY ASH

3.1.1 Organic Concentrations

Ranges of concentrations of organic constituents in extracts determined by the DWE and TCLP test methods are presented in Tables 3-1 and 3-2. respectively, and in Table 3-3 for the DWE, EP, and TCLP test methods. The salient features of the data given in these tables are as follows:

- The data base for simulated leachability tests for fly ash is very limited. Of the references reviewed in this study, only two provide some data on concentrations of contaminants from fly-ash-extract tests.

- Based on the limited data base, it appears that

    - Concentrations of PCDDs, PCDFs, PCBs, and chlorinated benzenes are below the instrument detection limits for fly-ash extracts obtained by the DWE test method.

    - Concentrations of PCDD and PCDF homologs are below the instrument detection limits for fly ash extracts obtained by the TCLP test method, with concentrations of the least toxic PCDD and PCDF homologs (H_7CDD, OCDD, H_7CDF, and OCDF) registering slightly above the instrument detection limits.

- Concentrations of chlorophenols were detected in fly-ash extracts obtained by the DWE test method from ashes from incinerators equipped with wet/dry scrubbers and dry scrubbers. No concentrations of these contaminants were detected in fly ash from an incinerator equipped with fabric filter dust collectors (baghouses). According to Sawell et al., 1986, the chlorophenols change chemically to soluble chlorophenate salts in such incinerators.

- No detected concentrations of other organics (see Table 3-3) were found in fly ash extracts obtained by the DWE, EP, and TCLP test methods except trace concentrations of methoxy ethane and methoxy ethanol.

TABLE 3-1

RANGES OF EXTRACT CONCENTRATIONS OF ORGANIC CONSTITUENTS FROM MUNICIPAL WASTE INCINERATOR FLY ASH DETERMINED BY THE DEIONIZED WATER EXTRACTION PROCEDURE IN ng/g (ppb)

Constituent	Reference 62		
TOTAL PCDD	**ND**	**ND**	**ND**
TOTAL PCDF	**ND**	**ND**	**ND**
TOTAL PCB	**ND**	**ND**	**ND**
Chlorobenzenes	ND	ND	ND
Chlorophenols	71 - 675	149 - 419	ND
No. of Samples	6	4	6
Pollution Control	Wet Dry Scrubber	Dry Scrubber	Baghouse
Country	Canada	Canada	Canada

ND = Below detection limit

TABLE 3-2

RANGES OF EXTRACT CONCENTRATIONS OF PCDDs AND PCDFs FROM MUNICIPAL WASTE INCINERATOR FLY ASH DETERMINED BY THE TOXIC CHARACTERISTIC LEACHING PROCEDURE TEST IN ng/l (parts per trillion)

Constituent	Reference 63
TCDD	<0.056-<0.094
PCDD	<0.040-<0.056
HCDD	<0.019-<0.027
H_7CDD	<0.038-0.11
OCDD	<0.078-0.11
2,3,7,8-TCDD	<0.056-<0.094
Total PCDD	0-0.188
TCDF	<0.048-<0.120
PCDF	<0.016-<0.026
HCDF	<0.013-<0.020
H_7CDF	<0.020-0.063
OCDF	<0.015-0.089
2,3,7,8-TCDF	<0.048-<0.120
Total PCDF	0-0.152
Number of Samples	4
Country	USA

TABLE 3-3

RANGES OF EXTRACT CONCENTRATIONS OF ORGANIC CONSTITUENTS FROM MUNICIPAL WASTE INCINERATOR FLY ASH FOR THE THREE LEADING EXTRACTION PROCEDURES IN µg/l (ppb)

Constituents	Reference 63			
	Deionized Water Extraction Procedure		Extraction Procedure Test	Toxic Characteristic Leaching Procedure
	First Extraction	Second Extraction		
Naphthalene	ND	ND	ND	ND
Methyl Naphthalene	ND	ND	ND	ND
Dimethyl Propdiol	ND	ND	ND	ND
Methyoxy Ethane	ND	ND	ND	ND-10
Methoxy Ethanol	ND	ND	ND	ND-10
No. of times found indicated by measurable value	none out of 4	none out of 4	none out of 4	2 out of 4
Country	USA	USA	USA	USA

ND = Below detection limit

- The limited data indicate the presence of very few, if any, concentrations of organics such as PCDDs, PCDFs, PCBs, and naphthalenes in extracts from fly ash.

- Data regarding simulated leachability extraction tests for fly ash originate from only North American (USA and Canada) studies.

3.1.2 Inorganic Constituent Concentrations

Ranges of concentrations of inorganic constituents in fly-ash extracts determined by the DWE, EP, and TCLP test methods are given in Tables 3-4, 3-6, and 3-8, respectively. Detailed concentrations for each pertinent reference are included in Tables 3-5, and 3-7 for the DWE and EP test methods respectively. The salient features of the data presented in these tables are listed below:

- Inorganic constituents, including heavy metals, are found in MSW incinerator fly-ash extract in varied concentrations. This conclusion applies to each of the three leachability test methods employed.

- The extract concentrations of cadmium, chromium, and lead obtained by the DWE and EP test methods exceed the EP toxicity maximum allowable limits by a wide margin. Extract concentrations of cadmium and lead obtained by the TCLP test method, exceed the EP toxicity maximum allowable limits by a wide margin.

- Occasionally, concentrations of inorganic constituents in extracts obtained by the DWE test method exceed the corresponding concentrations in extracts obtained by the EP or the TCLP test methods.

- In general, extract concentrations of many of the inorganic constituents under consideration are comparable for both the EP and the TCLP test methods.

- Extract data for inorganic constituent leachate concentrations from fly ash were obtained from studies in the USA and from one study in Canada.

TABLE 3-4

RANGES OF EXTRACT CONCENTRATIONS OF INORGANIC CONSTITUENTS FROM MUNICIPAL WASTE INCINERATOR FLY ASH DETERMINED BY THE DEIONIZED WATER EXTRACTION PROCEDURE TEST IN mg/l (ppm)

Constituent	Concentration	EP Tox. Max. Allowable Limit	References
Arsenic	0.005-0.005	5.0	63
Barium	0.19-1.68	100.0	45
Cadmium	ND-33	1.0	6, 45, 62, 63
Chromium	0.0025-176	5.0	6, 45, 62, 63
Lead	ND-150,000	5.0	6, 45, 62, 63
Mercury	0.00002-0.02	0.2	6, 63
Selenium	0.0025-0.108	1.0	63
Silver	0.02-0.05	5.0	45
Aluminum	0.09-0.25		45
Beryllium	0.01-0.01		45
Boron	ND-2100		45, 62
Calcium	896-4620		45
Cobalt	ND-0.12		6, 45, 62
Copper	0.0025-1240		6, 45, 62, 63
Iron	0.0025-0.167		45, 63
Lithium	0.27-0.38		45
Magnesium	0.03-37.6		45
Manganese	0.0005-0.052		45, 63
Molybdenum	0.22-0.34		45
Nickel	ND-420		6, 45, 62, 63
Potassium	702-2530		45
Sodium	587-971		45
Strontium	2.6-17.7		45

TABLE 3-4
RANGES OF EXTRACT CONCENTRATIONS OF INORGANIC CONSTITUENTS FROM MUNICIPAL WASTE INCINERATOR FLY ASH DETERMINED BY THE DEIONIZED WATER EXTRACTION PROCEDURE TEST IN mg/l (ppm)
PAGE TWO

Constituent	Concentration	EP Tox. Max. Allowable Limit	References
Tin	0.09-0.09		45
Titanium	0.05-0.05		45
Vanadium	0.02-0.02		45
Yttrium	0.05-0.05		45
Zinc	0.0015-2,000		6, 45, 62, 63
Country			USA, Canada

ND = Below detection limit

TABLE 3-5

EXTRACT CONCENTRATIONS OF INORGANIC CONSTITUENTS FROM MUNICIPAL WASTE INCINERATOR FLY ASH DETERMINED BY THE DEIONIZED WATER EXTRACTION PROCEDURE TEST IN mg/l (ppm)

Constituent	Reference 63	Reference 45
Arsenic	0.005 - 0.005	
Barium		0.19 - 1.68
Cadmium	0.005 - 0.122	0.03 - 0.17
Chromium	0.0025 - 0.15	0.04 - 0.08
Lead	0.025 - 0.148	0.26 - 35.0
Mercury	0.01 - 0.02	
Selenium	0.0025 - 0.108	
Silver		0.02 - 0.05
Aluminum		0.09 - 0.25
Beryllium		0.01 - 0.01
Boron		1.79 - 3.54
Calcium		896 - 4,620
Cobalt		0.03 - 0.03
Copper	0.0025 - 0.089	0.02 - 0.02
Iron	0.0025 - 0.167	0.03 - 0.03
Lithium		0.27 - 0.38
Magnesium		0.03 - 37.6
Manganese	0.0005 - 0.052	0.01 - 0.01
Molybdenum		0.22 - 0.34
Nickel	0 - 0.022	0.09 - 0.09
Potassium		702 - 2,530
Sodium		587 - 971
Strontium		2.60 - 17.70
Tin		0.09 - 0.09
Titanium		0.05 - 0.05
Vanadium		0.02 - 0.02
Yttrium		0.05 - 0.05
Zinc	0.0015 - 1.22	0.67 - 4.15
Chloride		
Sulfate		
Pollution Control	Mechanical Separators and ESP	Not Given
No. of Samples	8	2 - 28
Country	USA	USA

TABLE 3-5
EXTRACT LEACHATE CONCENTRATIONS OF INORGANIC CONSTITUENTS
FROM MUNICIPAL WASTE FLY ASH DETERMINED BY THE DEIONIZED WATER EXTRACTION PROCEDURE TEST IN mg/l (ppm)
PAGE TWO

Constituent	Reference 6	Reference 61					Reference 62		
		6.0 µm	2.4 µm	1.5 µm	0.05 µm	0.37 µm			
Arsenic									
Barium									
Cadmium	33	0.395	13.4	53	252	527	0-3	0	1-3
Chromium	<0.01						22-132	44-176	44-77
Lead	0.45	7.71	12.0	283	2,426	4,720	0-4,100	0-4,100	220-150,000
Mercury	0.00002								
Selenium									
Silver									
Aluminum									
Beryllium									
Boron							0-280	0 - 700	350-2,100
Calcium									
Cobalt	0.12						0	0	ND
Copper	1.7	<3.14	<5.35	<14.0	76.2	292	170-320	150-170	460-1,240
Iron									
Lithium									
Magnesium									

TABLE 3-5
EXTRACT LEACHATE CONCENTRATIONS OF INORGANIC CONSTITUENTS
FROM MUNICIPAL WASTE FLY ASH DETERMINED BY THE DEIONIZED WATER EXTRACTION PROCEDURE TEST IN mg/l (ppm)
PAGE THREE

Constituent	Reference 6	Reference 61					Reference 6		
		6.0 µm	2.4 µm	1.5 µm	0.05 µm	0.37 µm			
Manganese		2.43	4.0	74.0	119	36.8			
Molybdenum									
Nickel	0.10						0	0 - 420	0
Potassium		630	2,260	11,100	24,000	38,000			
Sodium		1,920	6,700	29,200	63,600	82,400			
Strontium									
Tin									
Titanium									
Vanadium									
Yttrium									
Zinc	884						0 - 1,400	0 - 2,000	
pH	6.2								
Chloride		2,310	6,310	16,000	33,700	64,900			
Sulfate		110,000	25,400	40,800	66,200	76,000			
No. of Samples		Not given	Not given	Not given	Not given	Not given	6	4	6
Pollution Control	Not given	Not given					Wet/Dry Scrubber	Dry Scrubber	Baghouse
Country	USA	USA	USA	USA	USA	USA	Canada	Canada	Canada

TABLE 3-6

RANGES OF EXTRACT CONCENTRATIONS OF INORGANIC CONSTITUENTS FROM MUNICIPAL WASTE INCINERATOR FLY ASH DETERMINED BY THE EXTRACTION PROCEDURE TEST IN mg/l (ppm)

Constituent	Concentration	EP Tox. Max. Allowable Limit	References
Arsenic	0.002-0.05	5.0	45, 63
Barium	0.067-22.8	100.0	45
Cadmium	0.025-18	1.0	45, 63
Chromium	0.0025-0.135	5.0	45, 63
Lead	0.019-53.35	5.0	45, 63
Mercury	ND-0.007	0.2	45, 63
Selenium	0.003-0.085	1.0	45, 63
Silver	0.001-0.051	5.0	45
Aluminum	0.159-18.8		45
Beryllium	0.005-0.005		45
Boron	1.53-6.53		45
Calcium	1,150-5,810		45
Cobalt	0.025-0.114		45
Copper	0.033-10.6		45, 63
Iron	0.0025-0.49		45, 63
Lithium	0.261-0.455		45
Magnesium	0.093-149		45
Manganese	0.005-8.03		45, 63
Molybdenum	0.10-0.229		45
Nickel	0.09-2.9		45, 63
Potassium	616-2,170		45
Sodium	506-821		45
Strontium	3.5-16		45
Tin	0.09-0.09		45

TABLE 3-6
RANGES OF EXTRACT CONCENTRATIONS OF INORGANIC CONSTITUENTS FROM MUNICIPAL WASTE INCINERATOR FLY ASH DETERMINED BY THE EXTRACTION PROCEDURE TEST IN mg/l (ppm)
PAGE TWO

Constituent	Concentration	EP Tox. Max. Allowable Limit	References
Titanium	0.05-0.05		45
Vanadium	0.015-0.015		45
Yttrium	0.05-0.05		45
Zinc	3.36-768		45, 63
Countries			USA

ND = Below detection limit

TABLE 3-7

EXTRACT CONCENTRATIONS OF INORGANIC CONSTITUENTS FROM MUNICIPAL WASTE INCINERATOR FLY ASH DETERMINED BY THE EXTRACTION PROCEDURE TEST IN mg/l (ppm)

Constituent	Reference 63	Reference 45
Arsenic	0.005 - 0.005	0.002 - 0.05
Barium		0.067 - 22.80
Cadmium	6.02 - 18	0.025 - 17.40
Chromium	0.0025 - 0.038	0.006 - 0.135
Lead	4.72 - 25.2	0.019 - 53.35
Mercury	0.004 - 0.004	ND - 0.007
Selenium	0.025 - 0.025	0.003 - 0.085
Silver		0.001 - 0.051
Aluminum		0.159 - 18.80
Beryllium		0.005 - 0.005
Boron		1.530 - 6.530
Calcium		1,150 - 5,810
Cobalt		0.025 - 0.114
Copper	0.041 - 1.62	0.033 - 10.60
Iron	0.0025 - 0.49	0.189 - 0.202
Lithium		0.261 - 0.455
Magnesium		0.093 - 149
Manganese	2.71 - 8.03	0.005 - 5.79
Molybdenum		0.100 - 0.229
Nickel	0.137 - 1.92	0.090 - 2.9
Potassium		616 - 2,170
Sodium		506 - 821
Strontium		3.5 - 16
Tin		0.09 - 0.09
Titanium		0.05 - 0.05
Vanadium		0.015 - 0.015
Yttrium		0.05 - 0.05
Zinc	186 - 726	3.36 - 768
Pollution Control	Mechanical Separators and ESP	Not Given
No. of Samples	4	2 - 14
Country	USA	USA

ND = Below detection limit
Blank = Not reported

TABLE 3-8

RANGES OF EXTRACT CONCENTRATIONS OF INORGANIC CONSTITUENTS FROM MUNICIPAL WASTE INCINERATOR FLY ASH DETERMINED BY THE TOXIC CHARACTERISTIC LEACHING PROCEDURE TEST IN mg/l (ppm)

Constituent	Reference 63	Reference 45		EP Tox. Max. Allowable Limit
		Fluid #1	Fluid #2	
Arsenic	0.005 - 0.111			5.0
Barium		0.38 - 1.48	0.5 - 1.86	100.0
Cadmium	0.015 - 17.2	0.03 - 18.8	0.03 - 20.3	1.0
Chromium	0.0025 - 0.544	0.02 - 0.12	0.02 - 0.03	5.0
Lead	0.025 - 15.2	6.10 - 26.8	5.3 - 36.6	5.0
Mercury	0.004 - 0.004			0.2
Selenium	0.0025 -0.025			1.0
Silver		0.02 - 0.07	0.02 - 0.08	5.0
Aluminum		0.21 - 16.0	0.09 - 0.09	
Beryllium		0.01 - 0.01	0.01 - 0.01	
Boron		1.36 - 7.3	1.79 - 5.94	
Calcium		1,450 - 5,390	1,210 - 5,070	
Cobalt		0.03 - 0.14	0.03 - 0.06	
Copper	0.0025 - 0.201	0.02 - 14.70	0.02 - 1.08	
Iron	0.0025 - 190	0.03 - 0.17	0.03 - 0.03	
Lithium		0.25 - 0.55	0.28 - 0.53	
Magnesium		0.06 - 171	0.04 - 109.0	
Manganese	0.049 - 14.7	0.01 - 7.19	0.01 - 3.28	
Molybdenum		0.10 - 0.28	0.10 - 0.31	
Nickel	0.0075 - 1.52	0.09 - 2.48	0.09 - 0.63	
Potassium		574 - 2,390	708 - 2,780	
Sodium		474 - 922	1,950 - 2,500	
Strontium		3.97 - 14.6	3.4 - 17.30	
Tin		0.09 - 0.09	0.09 - 0.09	
Titanium		0.05 - 0.05	0.05 - 0.05	
Vanadium		0.02 - 0.02	0.02 - 0.02	
Yttrium		0.05 - 0.05	0.05 - 0.05	
Zinc	0.151 - 746	2.27 - 885	384 - 621	
No. of Samples	4	2 - 3	2 - 3	
Country	USA	USA	USA	

Blank = Not reported

3.2 BOTTOM ASH

3.2.1 Organic Concentrations

Ranges of concentrations of organic constituents in extracts of bottom ash determined by the three extraction procedures, DWE, EP, and TCLP, are presented in Table 3-9. The following list provides the salient features of the data in this table.

- The data base for simulated leachability tests for bottom ash is very limited. Of the references reviewed in this study, only one provides some data on concentrations of contaminants from simulated leachability tests for bottom ash.

- Concentrations of most of the organics analyzed for were below the detection limit. Several contaminants were detected in minute concentrations in bottom-ash extracts obtained by the DWE test method (phenol, for example). Extracts obtained by the EP and the TCLP test methods resulted in only one contaminant, methoxy ethane, at minute concentrations above the instrument detection limits.

- The limited data indicate that very few, if any, concentrations of organics are present in extracts from bottom ash.

- There is an indication of the occurrence of some organics in extracts from bottom ash that do not occur in extracts from fly ash.

- The data about simulated leachability extraction tests for bottom ash is available only from the U.S. studies.

TABLE 3-9

RANGES OF EXTRACT CONCENTRATIONS OF ORGANIC CONSTITUENTS FROM MUNICIPAL WASTE INCINERATOR BOTTOM ASH FOR THREE LEACHING PROCEDURES IN µg/l (ppb)

Constituents	Reference 63			
	Deionized Water Extraction Procedure		Extraction Procedure	Toxic Characteristic Leaching Procedure
	First Extraction	Second Extraction		
Naphthalene	ND	ND	ND	ND
Methyl Naphthalene	ND	ND	ND	ND
Dimethyl Prodiol[1]	ND	ND	ND	ND
Methyoxy Ethane[2]	ND-10	ND	ND-12	ND-22
Phenol	ND-28	ND	ND	ND
E. Dim Dioxane[3]	ND	ND	ND	ND
Bis oxy Ethanol[4]	ND	ND	ND	ND
Oleyl Alcohol[5]	ND	ND	ND	ND
Ethoxy Ethanol[6]	ND	ND	ND	ND
Cycloocta Decone[7]	ND-150	ND	ND	ND
M. Furan Dione[8]	ND-6	ND	ND	ND
Benzoic Acid	ND-46	ND	ND	ND
No. of times found indicated by measureable value	1 out of 1	1 out of 1	1 out of 1	1 out of 1
Country	USA	USA	USA	USA

ND = Below detection limit
CAS = Chemical Abstract Services

1. 2,2-Dimethyl-1,3-propanediol (CAS 126-30-7)
2. 1-Methoxy-2-(methoxy methoxy)ethane (9Cl)(CAS 74498-88-7)
3. 5-Ethyl-2,2-dimethyl-1,3-dioxane (9CL)(CAS 25796-26-3)
4. 2,2-[1,2-Ethanediylbis(oxy)]bis-ethanol (CAS 112-27-6)
5. (2)-9-Octadecen-1-Ol (CAS 143-28-2)
6. 2-[2-(Ethenyloxy)ethoxy]-ethanol (CAS 929-37-3)
7. 1,4,7,10,13,16-Hexaoxacyclooctadecane (CAS 17455-13-9)
8. 3,4-Dimethyl-2-5-furandione (CAS 766-39-2)

3.2.2 Inorganic Constituent Concentrations

Ranges of concentrations of inorganic constituents in extractions of bottom ash determined by the DWE test method are presented in Table 3-10. The salient features of the data in this table are as follows:

- The data base for simulated leachability tests for bottom ash is very limited. Of the references reviewed in this study, only one provides some data on inorganic concentrations based on a simulated leachability test for bottom ash.
- Of the few inorganic constituents analyzed, in general, the concentrations are below the instrument detection limits, or are very low. This is consistent with the reported low concentrations of inorganic constituents in bottom ash.
- Extract concentrations of inorganic constituents regulated under RCRA are below the instrument detection limits.

3.3 COMBINED BOTTOM AND FLY ASH

3.3.1 Organic Concentrations

Ranges of concentrations of PCDDs and PCDFs in extracts from combined ash determined by the DWE test method are presented in Table 3-11. Ranges of concentrations of other organics in extracts from combined ash determined by the DWE, EP, and TCLP test methods are presented in Table 3-12. The salient features of the data presented in these tables follow:

- The data base for simulated leachability for combined ash is very limited. Of the references reviewed in this study, only one provides some data on combined ash extract concentrations.

TABLE 3-10

EXTRACT CONCENTRATIONS OF INORGANIC CONSTITUENTS FROM MWC BOTTOM ASH DETERMINED BY THE DEIONIZED WATER EXTRACTION TEST IN mg/l (ppm)

Constituent	EP Toxicity Maximum Allowable Limits	Reference 6
Arsenic	5.0	
Barium	100.0	
Cadmium	1.0	<0.01
Chromium	5.0	<0.01
Lead	5.0	<0.03
Mercury	0.2	ND
Selenium	1.0	
Silver	5.0	
Cobalt		<0.02
Copper		0.04
Nickel		<0.05
Zinc		0.13
pH		8.9
No. of Samples		Not given
Pollution Control		Not given
Country		Canada

ND = Below detection limit
Blank = Not reported

TABLE 3-11

RANGES OF EXTRACT CONCENTRATIONS OF PCDDs AND PCDFs FROM MUNICIPAL WASTE INCINERATOR COMBINED FLY AND BOTTOM ASH DETERMINED BY THE TOXIC CHARACTERISTIC LEACHING PROCEDURE TEST IN ng/l (parts per trillion)

Constituent	Reference 63
TCDD	<0.038-<0.230
PCDD	<0.023-<0.067
HCDD	<0.015-<0.044
H_7CDD	<0.028-<0.120
OCDD	<0.035-0.091
2,3,7,8-TCDD	<0.038-<0.230
Total PCDD	ND-0.091
TCDF	<0.031-<0.200
PCDF	<0.013-<0.042
HCDF	<0.008-<0.025
H_7CDF	<0.013-0.043
OCDF	<0.060-0.054
2,3,7,8-TCDF	<0.031-<0.200
Total PCDF	ND-0.054
Number of Samples	4
Country	USA

ND = Below detection limit

TABLE 3-12

RANGES OF EXTRACT CONCENTRATION OF ORGANIC CONSTITUENTS FROM MUNICIPAL WASTE INCINERATOR COMBINED FLY AND BOTTOM ASH FOR THREE LEADING PROCEDURES IN µg/l (ppb)

Constituents	Reference 63			
	Deionized Water Extraction Procedure		Extraction Procedure Test	Toxic Characteristic Leaching Procedure
	First Extraction	Second Extraction		
Naphthalene	ND	ND	ND-8	ND
Methyl Naphthalene	ND-80	ND	ND-18	ND
Oleyl Alcohol	ND-88	ND	ND	ND
Methyoxy Ethane	ND	ND	ND	ND
Methoxy Ethanol	ND	ND-6	ND	ND-13
Dimethyl Propdiol	ND-160	ND-140	ND-190	ND-140
Phenol	ND	ND-33	ND	ND
Bis oxy Ethanol	ND-96	ND-18	ND	ND
Ethoxy Ethanol	ND-310	ND-390	ND	ND
Cycloocta Decone	ND-580	ND-1200	ND	ND
M. Furan dione	ND	ND	ND	ND
E. Dim Dioxane	ND-510	ND	ND	ND
Benz, Di Carboxy A	ND	ND-2	ND	ND
No. of times found indicated by measureable value	1 out of 3	1 out of 3	1 out of 3	1 out of 3
Country	USA	USA	USA	USA

ND = Below detection limit

- Based on the limited data base, it appears that
  - Concentrations of PCDD and PCDF homologs are below the instrument detection limits for combined ash extracts obtained by the TCLP test method except OCDD, HCDF, H_7CDF, and OCDF homologs, for which low extract concentrations were detected.
  - The concentrations of other organics such as naphthalene, phenol, and ethanol are minute or below the instrument detection limits.
  - In most cases, when minute concentrations of organics are listed, their occurrences are 1 out of 3. This means that the number of times concentrations were not detected exceeded the number of times they were detected in all cases.
- The limited data indicate that very few, if any, organics such as PCDDs, PCDFs, and naphthalenes are present in extracts from combined ash.
- The data regarding simulated leachability extraction tests for combined ash originate only from U.S. studies.

3.3.2 Inorganic Constituent Concentrations

Ranges of concentrations of inorganic constituents in combined ash extracts determined by the DWE, EP, and TCLP test methods are given in Table 3-13, 3-15, and 3-17, respectively. Detailed concentrations for each pertinent reference are included in Tables 3-14 and 3-16 for the DWE and EP test methods, respectively. The following are the salient features of the data presented in these tables:

- Inorganic constituents, including heavy metals, are found in MSW incinerator combined ash extracts in varied concentrations. This conclusion applies to each of the three leachability test methods employed.

TABLE 3-13

RANGES OF EXTRACT CONCENTRATIONS OF INORGANIC CONSTITUENTS FROM MUNICIPAL WASTE INCINERATOR COMBINED FLY ASH AND BOTTOM ASH DETERMINED BY THE DEIONIZED WATER EXTRACTION PROCEDURE TEST IN mg/l (ppm)

Constituent	Concentration	EP Tox. Max. Allowable Limit	References
Arsenic	0.005-0.05	5.0	45, 63
Barium	0.15-0.39	100.0	45
Cadmium	0.005-0.03	1.0	45, 63
Chromium	0.0025-0.02	5.0	45, 63
Lead	0.025-2.98	5.0	45, 63
Mercury	0.01-0.1	0.2	45, 63
Selenium	0.0025-0.05	1.0	45, 63
Silver	ND-0.05	5.0	45
Aluminum	0.17-29.4		45
Beryllium	ND-0.01		45
Boron	0.1-0.22		45
Calcium	122-536		45
Cobalt	0.01-0.03		45
Copper	0.0025-0.19		45, 63
Iron	0.0025-0.038		45, 63
Lithium	0.01-0.05		45
Magnesium	ND-0.19		45
Manganese	ND-0.01		45, 63
Molybdenum	0.07-0.1		45
Nickel	0.0075-0.09		45, 63
Potassium	85.2-120		45
Sodium	68.3-85.3		45
Strontium	0.58-3.19		45
Tin	0.02-0.09		45

TABLE 3-13
RANGES OF EXTRACT CONCENTRATIONS OF INORGANIC CONSTITUENTS FROM MUNICIPAL WASTE INCINERATOR COMBINED FLY ASH AND BOTTOM ASH DETERMINED BY THE DEIONIZED WATER EXTRACTION PROCEDURE TEST IN mg/l (ppm)
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Constituent	Concentration	EP Tox. Max. Allowable Limit	References
Titanium	0.01-0.05		45
Vanadium	0.02-0.03		45
Yttrium	0.01-0.05		45
Zinc	0.0015-0.96		45, 63
Chloride	209-644		45
Sulfate	156-571		45
Country			USA

TABLE 3-14

EXTRACT CONCENTRATIONS OF INORGANIC CONSTITUENTS FROM MUNICIPAL WASTE INCINERATOR COMBINED FLY AND BOTTOM ASH DETERMINED BY THE DEIONIZED WATER EXTRACTION PROCEDURE TEST IN mg/l (ppm)

Constituent	Reference 63	Reference 45
Arsenic	0.005 - 0.005	0.05 - 0.05
Barium		0.15 - 0.39
Cadmium	0.005 - 0.005	0.01 - 0.03
Chromium	0.0025 - 0.005	0 - 0.02
Lead	0.025 - 0.063	0.05 - 2.98
Mercury	0.01 - 0.01	0.10 - 0.10
Selenium	0.0025 - 0.025	0.05 - 0.05
Silver		0 - 0.05
Aluminum		0.17 - 29.4
Beryllium		0 - 0.01
Boron		0.10 - 0.22
Calcium		122 - 536
Cobalt		0.01 - 0.03
Copper	0.0025 - 0.07	0.11 - 0.19
Iron	0.0025 - 0.038	0.03 - 0.03
Lithium		0.01 - 0.05
Magnesium		0 - 0.19
Manganese	0.0005 - 0.0021	0 - 0.01
Molybdenum		0.07 - 0.10
Nickel	0.0075 - 0.0075	0.02 - 0.09
Potassium		85.2 - 120
Sodium		68.3 - 85.3
Strontium		0.58 - 3.19
Tin		0.02 - 0.09
Titanium		0.01 - 0.05
Vanadium		0.02 - 0.03
Yttrium		0.01 - 0.05
Zinc	0.0015 - 0.067	0.38 - 0.96
Chloride		209 - 644
Sulfate		156 - 571
No. of Samples	8	2 - 28
Country	USA	USA

TABLE 3-15

RANGES OF EXTRACT CONCENTRATIONS OF INORGANIC CONSTITUENTS FROM MUNICIPAL WASTE INCINERATOR COMBINED FLY AND BOTTOM ASH DETERMINED BY THE EXTRACTION PROCEDURE TEST IN mg/l (ppm)

Constituent	Concentration	EP Tox. Max. Allowable Limit	References
Arsenic	0.005-0.1	5.0	45, 63
Barium	0.027-6.3	100.0	45
Cadmium	0.01-3.94	1.0	45, 63
Chromium	0.0059-0.46	5.0	45, 63
Lead	0.02-34	5.0	45, 63
Mercury	ND-6.0	0.2	45, 63
Selenium	0.002-0.10	1.0	45, 63
Silver	0.001-0.10	5.0	45, 63
Aluminum	31.9-43.8		45
Beryllium	0.005-0.005		45
Boron	1.23-2.33		45
Calcium	77-1,740		45
Cobalt	0.050-0.057		45
Copper	0.039-1.19		45, 63
Iron	4.5-143		45, 63
Lithium	0.063-0.093		45
Magnesium	22.8-42.7		45
Manganese	3.6-6.24		45, 63
Molybdenum	0.10-0.10		45
Nickel	0.241-2.03		45, 63
Potassium	10-154		45
Sodium	89.9-100		45
Strontium	2.45-4.9		45
Tin	0.09-0.09		45

TABLE 3-15
RANGES OF EXTRACT CONCENTRATION OF INORGANIC CONSTITUENTS FROM MUNICIPAL WASTE INCINERATOR COMBINED FLY AND BOTTOM ASH DETERMINED BY THE EXTRACTION PROCEDURE TEST IN mg/l (ppm)
PAGE TWO

Constituent	Concentration	EP Tox. Max. Allowable Limit	References
Titanium	0.05-0.05		45
Vanadium	0.015-0.015		45
Yttrium	0.05-0.05		45
Zinc	38.5-726		45, 63
Chloride	78-952		45
Sulfate	85-1,150		45
Country			USA

TABLE 3-16

EXTRACT CONCENTRATIONS OF INORGANIC CONSTITUENTS FROM MUNICIPAL WASTE INCINERATOR COMBINED FLY AND BOTTOM ASH DETERMINED BY THE EXTRACTION PROCEDURE TEST IN mg/l (ppm)

Constituent	Reference 63	Reference 45
Arsenic	0.005 - 0.005	0.002 - 0.10
Barium		0.027 - 6.3
Cadmium	0.06 - 0.827	0.010 - 3.94
Chromium	0.0059 - 0.15	0.006 - 0.46
Lead	2.09 - 34	0.020 - 21
Mercury	0.004 - 0.004	0 - 6.0
Selenium	0.025 - 0.025	0.002 - 0.10
Silver		0.001 - 0.10
Aluminum		31.9 - 43.80
Beryllium		0.005 - 0.005
Boron		1.23 - 2.33
Calcium		77 - 1,740
Cobalt		0.050 - 0.057
Copper	0.039 - 1.19	0.713 - 0.898
Iron	4.5 - 143	94.3 - 96.5
Lithium		0.063 - 0.093
Magnesium		22.8 - 42.7
Manganese	3.6 - 6.24	5.62 - 6.21
Molybdenum		0.10 - 0.10
Nickel	0.241 - 0.415	0.463 - 2.03
Potassium		105 - 154
Sodium		89.9 - 100
Strontium		2.45 - 4.9
Tin		0.09 - 0.09
Titanium		0.05 - 0.05
Vanadium		0.015 - 0.015
Yttrium		0.05 - 0.05
Zinc	38.5 - 726	64.5 - 81
Chloride		78 - 952
Sulfate		85 - 1,150
No. of Samples	3	2 - 66
Country	USA	USA

Blank = Not reported

TABLE 3-17

RANGES OF EXTRACT CONCENTRATIONS OF INORGANIC CONSTITUENTS FROM MUNICIPAL WASTE INCINERATOR COMBINED FLY AND BOTTOM ASH DETERMINED BY THE TOXIC CHARACTERISTIC LEACHING PROCEDURE TEST IN mg/l (ppm)

Constituent	Reference 63	Reference 45		EP Tox. Max. Allowable Limit
		Fluid #1	Fluid #2	
Arsenic	0.005 - 0.037	0.01 - 0.03	0.01 - 0.10	5.0
Barium		0.10 - 3.2	0.05 - 0.63	100.0
Cadmium	0.025 - 3.32	0.03 - 1.9	0.01 - 0.47	1.0
Chromium	0.025 - 0.439	0.2 - 0.32	0.01 - 0.16	5.0
Lead	0.655 - 30.1	0.9 - 47	0.05 - 6.10	5.0
Mercury	0.004 - 0.004	0.05 - 0.06	0.00 - 0.10	0.2
Selenium	0.0025 - 0.025	0.01 - 0.01	0.01 - 0.05	1.0
Silver		0.02 - 0.04	0.01 - 0.05	5.0
Aluminum		30.8 - 32.8	0.09 - 0.09	
Beryllium		0.01 - 0.01	0.01 - 0.01	
Boron		2.53 - 2.89	1.75 - 1.77	
Calcium		1,930 - 1,990	362 - 1,430	
Cobalt		0.05 - 0.05	0.03 - 0.03	
Copper	0.0025 - 0.019	0.05 - 0.09	0.02 - 0.02	
Iron	0.828 - 60.6	183 - 230	2.18 - 6.33	
Lithium		0.09 - 0.10	0.06 - 0.06	
Magnesium		41.7 - 41.8	0.14 - 27.9	
Manganese	4.2 - 11.9	7.04 - 7.47	3.22 - 3.34	
Molybdenum		0.10 - 0.10	0.10 - 0.10	
Nickel	0.346 - 0.805	0.33 - 0.41	0.09 - 0.09	
Potassium		106 - 111	86.5 - 93.9	
Sodium		103 - 110	1,410 - 1,500	
Strontium		5.34 - 5.47	3.94 - 4.01	
Tin		0.09 - 0.09	0.09 - 0.09	
Titanium		0.05 - 0.08	0.05 - 0.05	
Vanadium		0.05 - 0.06	0.02 - 0.02	
Yttrium		0.05 - 0.05	0.05 - 0.05	
Zinc	23.3 - 373	72.2 - 83.2	23.5 - 32	
Chloride			302 - 625	
Sulfate			260 - 1,450	
No. of Samples		2 - 7	2 - 34	
Country	USA	USA	USA	

Blank = Not reported

- The extract concentrations of RCRA-regulated inorganic constituents obtained by the DWE test method are below the EP toxicity maximum allowable unit. EP extract concentrations of cadmium, lead, and mercury exceed the EP toxicity maximum allowable limit by a wide margin, and TCLP extract concentrations of cadmium and lead exceed EP toxicity maximum allowable unit by a wide margin.

- In general, EP and TCLP extract concentrations for combined ash are comparable for many of the constituents tested.

- In general, EP and TCLP extract concentrations for combined ash exceed those of the DWE extract concentrations for many of the constituents tested.

- In general, concentrations of inorganic constituents in combined-ash-extracts are lower than those for fly-ash extracts.

- Laboratory leachability data for inorganic constituent extract concentrations from combined ash are based only on U.S. studies.

4.0 CHARACTERIZATION OF LEACHATE FROM FIELD SAMPLES

Of prime importance are the measured concentrations of organic and inorganic constituents found in leachates from landfill disposal sites for MSW incinerator ashes (fly, bottom, and combined) and residues.

This section addresses concentrations of organic and inorganic constituents based on actual field leachate data collected from landfill disposal sites for MSW incinerator residues, also known as monofills. The information in this section was gathered from the U.S. and European leachate data found in the literature reviewed, as well as from the results of the recently conducted EPA study.

In contrast to data presented in Sections 2.0 and 3.0 on ash characterization and extract data which addressed constituent concentrations by the type of ashes (fly, bottom, combined), the actual field data represent leachates from MSW incinerator residues. In addition to the fly, bottom, and combined ashes, the residues may include glass and various types of metals that were removed before or after combustion of the refuse. Thus, no direct correlation can be drawn between the data presented in this section and the data presented in the previous sections.

This section is divided by the types of contaminants found in leachates rather than by concentrations in different types of ashes.

4.1 ORGANIC CONCENTRATIONS

Ranges of PCDDs, PCDFs, and PCBs and of other organic concentrations in leachates are presented in Tables 4-1 and 4-2, respectively. The salient features of the data given in these tables are as follows:

- The data base for leachate concentrations of organic constituents is very limited. Of the references reviewed in the course of this study, only one study, the EPA-sponsored study conducted by Versar, provides data on concentrations of organic contaminants from leachate of MSW incinerator residues. The Versar Study is provided in its entirety in Volume V of this report.

TABLE 4-1

RANGES OF LEACHATE CONCENTRATIONS OF PCDDs, PCDFs, AND PCBs FROM SOLID MUNICIPAL WASTE INCINERATOR RESIDUES DETERMINED FROM LEACHATE FIELD SAMPLES IN ng/l (parts per trillium)

Constituent	Reference 63
T_4CDD	0.025-28
PCDD	0.015-93
HCDD	0.01-130
H_7CDD	0.009-172
OCDD	0.06-120
2,3,7,8-TCDD	0.025-1.6
Total PCDD	0.06-543
T_4CDF	0.025-65
PCDF	0.01-64
HCDF	0.005-76
H_7CDF	0.015-60
OCDF	0.04-15
2,3,7,8-TCDF	0.025-11
Total PCDF	0.04-280
Mono CB	ND
Di CB	ND-2
Tri CB	ND-8
Tetra CB	ND
Penta CB	ND
Total PCB	ND-8
No. of Samples	9 from 3 facilities
No. of times found PCBs indicated by measured value	1 out of 9
Country	USA

CB = Chlorobiphenyl
ND = Below detection limit

TABLE 4-2

RANGES OF LEACHATE CONCENTRATIONS OF ORGANICS FROM MUNICIPAL SOLID WASTE INCINERATOR RESIDUES DETERMINED FROM LEACHATE FIELD SAMPLES IN µg/l (ppb)

Constituents	Reference 63	Instances Found
Ethyl Hexyl Phthalate[1]	ND-80	4 out of 9
Dimethyl Propane Diol[2]	ND-120	4 out of 9
Biphenyl	ND-51	2 out of 9
Hexa Tiepane[3]	ND-82	1 out of 9
Thiolane[4]	ND-400	2 out of 9
Benzaldehyde	ND-8	1 out of 9
Sulfonylbis Sulfur	ND-11	1 out of 9
No. of Samples	9	
Country	USA	

ND = Below Detection Limit
CB = Chlorobiphenyl

1. Bis(2-ethyl hexyl) phthalate (CAS 117-81-7)
2. 2,2-Dimethyl-1,3-propanediol (CAS 126-30-7)
3. Hexathiepane (CAS 17233-71-5)
4. 1,2,4-Trithiolane (CAS 289-16-7)

- Based on the limited available data, it appears that
  - PCDDs, PCDFs, and PCBs are found in leachates from MSW incinerator residues in varied concentrations. Maximum 2,3,7,8-TCDD and 2,3,7,8-TCDF concentrations are 1.6 and 11 ng/l (parts per trillion), respectively, and the maximum total PCB concentration is 8 ng/l (parts per trillion).
  - The highest measured PCDDs are 130 ng/l (parts per trillion) for HCDD and 172 ng/l (parts per trillion) for H_7CDD; the highest measured PCDFs are 76 ng/l (parts per trillion) for HCDF and 65 ng/l (parts per trillion) for T_4CDF.
  - The ranges of PCDDs and PCDFs concentrations are quite wide and cover several orders of magnitude.
  - Some of the PCB homologs are below the instrument detection limit, and only the Di- and Tri-CB homologs show concentrations above the instrument detection limits.
  - Concentrations of other organic constituents vary widely and their occurrence is very low. This means that the number of times organics were found in field leachate samples was always less than 50 percent of the sampling times.
- No good comparison can be made between simulated and actual leachability data because of the many limitations in design of the studies implemented, and because leachate data are based on MSW incinerator residues whereas extract data are given for each of the MSW incinerator ashes. However, based on the limited data available, it appears that the following are true:
  - The concentrations of PCDDs and PCDFs in leachates exceed those in extracts. This may indicate that additional factors unaccounted for in

the extractions are involved in leachate generation (Tables 3-1, 3-2, 3-11, and 4-1).

  - The limited data on PCBs in leachates and extracts are more consistent and reveal very low concentrations of total PCBs (Tables 3-1, and 4-1).

- Data regarding field leachate of organics from MSW incinerator residues found in the literature reviewed in this study are from the USA only.

4.2 INORGANIC CONSTITUENT CONCENTRATIONS

Ranges of inorganic constituent concentrations in field leachates are presented in Table 4-3. Table 4-4 provides detailed concentrations for each pertinent reference. The salient features of the data presented in these tables are as follows:

- Inorganic constituents, including heavy metals, are found in leachates from MSW incinerator residues in varied concentrations.

- For some of the constituents, the ranges of concentrations are quite wide, covering several orders of magnitude. The reasons for the wide variability are similar to those discussed in Section 2.1.1. In addition, climatological factors, disposal factors, and characteristics of landfill soils could affect data variability.

- The data base for field leachate concentrations of inorganic constituents is larger than that for organics, but should be considered limited because of the large number of factors that could affect the leachate concentrations.

- Based on the data available, inorganic constituent concentrations in field leachates are below the EP toxicity maximum allowable limits by a wide margin. This is in contrast to the extract data, which showed cadmium, chromium, and lead to exceed the EP toxicity maximum allowable limit by a wide margin, depending on the leachability extraction method employed and the type of ash leached.

TABLE 4-3

RANGES OF LEACHATE CONCENTRATIONS OF INORGANIC CONSTITUENTS FROM MUNICIPAL WASTE INCINERATOR RESIDUES DETERMINED FROM LEACHATE FIELD SAMPLES IN mg/l (ppm)

Constituent	Concentration	EP Toxicity Max. Allowable Limit	Primary Drinking Water Standards	References
Arsenic	0.005-0.218	5.0	0.050	63
Barium	1.0	100.0	1.000	26
Cadmium	ND-0.044	1.0	0.010	26, 63
Chromium	0.006-1.53	5.0	0.050	26, 58, 63
Lead	0.012-2.92	5.0	0.050	26, 58 ,63
Mercury	0.001-0.008	0.2	0.002	63
Selenium	0.0025-0.037	1.0	0.010	63
Silver	0.04	5.0	0.050	26
Calcium	21			58
Copper	0.022-24			26, 58, 63
Iron	0.168-121			26, 58, 63
Manganese	0.103-4.57			63
Nickel	ND-0.412			26, 63
Potassium	21.5			58
Sodium	200-4,000			26, 58
Zinc	ND - 3.3			26, 58, 63
Chloride	1,700-18,500			26, 58
Sulfate	94			58
pH	8.04-8.3			58, 63
TDS	11,300-28,900			26
Country				USA, Germany

ND = Below detection limit

TABLE 4-4
LEACHATE CONCENTRATIONS OF INORGANIC CONSTITUENTS FROM MUNICIPAL WASTE INCINERATOR RESIDUES DETERMINED FROM LEACHATE FIELD SAMPLES IN mg/l (ppm)

Constituent	Reference 58	Reference 26						Reference 63
Arsenic								0.005-0.218
Barium				1				
Cadmium		ND	ND		0.01	0.003		0.025-0.044
Chromium	1.53					0.006		0.025-0.914
Lead	1.16	0.012	0.25		0.06	0.033		0.025-2.92
Mercury								0.001-0.008
Selenium								0.0025-0.037
Silver		0.04						
Aluminum								
Beryllium								
Boron								
Calcium	21							
Cobalt								
Copper	1.15	24		1	0.05	0.022		0.045-2.57
Iron	4.95					0.168		0.758-121
Lithium								
Magnesium								

TABLE 4-4
LEACHATE CONCENTRATIONS OF INORGANIC CONSTITUENTS FROM MUNICIPAL WASTE INCINERATOR RESIDUES DETERMINED FROM LEACHATE FIELD SAMPLES IN mg/l (ppm)
PAGE TWO

Constituent	Reference 58	Reference 26						Reference 63
Manganese								0.103-4.57
Molybdenum								
Nickel		ND	ND		0.05			0.0075-0.412
Potassium	21.5							
Sodium	3,350		4,000	200				
Strontium								
Tin								
Titanium								
Vanadium								
Yttrium								
Zinc	0.95	0.025	ND		0.39	0.047		0.048-3.3
pH	8.3					8.04		
Chloride	1,803		18,500	1,700		7,500		
Sulfate	94							
TDS			28,900	11,300				
No. of Samples	Not given	Not given	Not given	Not given	Not given	Not given	Not given	9 from 3 incinerators
Country	Philadelphia, PA, USA	Vestskoven, Germany	Grobmehring, Germany	Lacy St, CA, USA	Saugus, MA, USA	Auburn, ME, USA	Philadelphia, PA, USA	USA

- In general, leachate concentrations of inorganic constituents appear to be lower than those obtained from extractions, depending on the test method employed.

- Data regarding field leachate of inorganic constituents from MSW incinerator residues found in the literature reviewed in this study originates from U.S. and German studies.

5.0 SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

This report provides a review of literature pertaining to the characterization of MSW incinerator residues and, in particular, of organic and inorganic content in test extracts and actual leachates of the incineration residues. The primary objectives of this report were to determine ranges of concentration of contaminants and MSW incinerator residues and the degree of their leachability. Sections 2.0, 3.0 and 4.0 of this report provide detailed information on contaminant concentrations in residues and leachate from MSW incinerator residues. This section highlights the findings in previous sections and delineates some data gaps and the need for additional information before definitive conclusions can be drawn regarding environmental effects of MSW incinerators residues.

Section 7.0 in Volume I of this report, Characterization of MWC Ashes and Leachates from MSW Landfills, Monofills, and Codisposal Sites, provides a detailed summary of this entire report. This section only summarizes the information obtained from the literature.

Summary and Conclusions

- PCDDs, PCDFs, PCBs, organics, and inorganic constituents are found in MSW ashes (fly, bottom, and combined ash) in varied concentrations. The highest concentrations of inorganic constituents, PCBs, PCDDs, and PCDFs are found in fly ash followed by combined ashes; the lowest levels are found in bottom ashes. The combined ashes and bottom ash contain higher levels of semivolatiles.

- PCDDs, PCDFs, PCBs, organics, and inorganic constituents are found in extracts of MSW residues (fly, bottom, and combined) and in varied concentrations.

- The TCLP method seems to be more aggressive for certain elements--arsenic, chromium, manganese, and mercury. One study reported that the TCLP Fluid #2 extracted mercury levels that did not meet the EP toxicity maximum allowable limit. Based on concentrations in extracts (not on fraction leached), the EP method appears to be slightly more efficient than the TCLP in extracting lead. The extraction efficiencies for the other metals were approximately equal for these two extraction methods.

- The TCLP was ineffective for extracting organic constituents, including PCDDs and PCDFs.

- In general, the EP and TCLP were more aggressive than the SW-924 method for extracting metals.

- Depending on the test method, extracts obtained from fly ash contained concentrations of cadmium, chromium, and lead that often exceeded the EP toxicity maximum allowable limit.

- PCDDs, PCDFs, and PCBs, organics, and inorganic constituents are found in leachates of MSW residues in varied concentrations.

- In general, PCDD, PCDF, and PCB concentrations are somewhat higher in leachates then in extracts, perhaps because of microbial activities. However, inorganic constitutent concentrations in leachates are, in general, lower than those in extracts. Inorganic constituent concentrations in leachates were always below the EP toxicity maximum allowable unit.

- The data base for characterizing MSW incinerator fly ash is quite substantial. It becomes limited for bottom and combined ashes. The data base for the extracts and actual leachates is very limited, and any conclusion drawn on this basis is tentative at best.

- The data presented in this report are based on the literature reviewed and are subject to the following caveats:

    - The great difference in the design and operating conditions of the incinerators involved.

    - The great variability in the composition of refuse burnt.

- The differences in disposal practices of the MSW incinerator refuse.

- The climatological differences from one site to another.

- The differences in sampling and handling techniques, and the analytical techniques.

- The inherent inaccuracies (both systematic and random) associated with the sampling, handling, and analytical techniques. One of the exceptions is the EPA-sponsored study conducted by Versar (Volume V), which adhered to very stringent QA/QC sampling, handling, and analytical protocols.

- The limited information in most of the literature reviewed regarding the analytical techniques and QA/QC procedures employed.

- The different design objectives of the studies reported in the literature, including performance evaluation of extraction and analysis techniques, ash characterization, leachate characterization, determination of environmental concerns, and assessment of compliance with standards.

Some of these factors could explain the wide variability of the data and, in some instances, the inconsistencies.

Recommendations

- It is apparent that none of the documents reviewed in this study were intended to perform a full and systematic evaluation of the discharges of contaminants from each stage of the MSW incineration cycle, and then to assess the effects of these discharges on various environmental media (soil, water, and air). The full-cycle study includes characterizing raw refuse, MSW incinerator discharges into air and water, (quench water, for example), and leachates from MSW incinerator ashes. Such studies are needed.

- Reference 47 provides an indication of the possible presence of PCDDs and PCDFs in raw municipal waste refuse via herbicidal formulations, treated wood, or PCB-containing products. This type of information could be vital in evaluating strategies for controlling discharges from MSW residues.

- It appears that several systematic studies are necessary to characterize discharges from the MSW incineration cycle and to expand the existing data base, in particular, the area of extraction and leachability tests.

- In assessing the potential effects of MSW incinerator discharges, it is important to perform a multimedia environmental assessment rather than evaluating the effects on one media at a time. This implies, for example, the need for considering the effects of both leachates and air discharges as demonstrated by the following example. Data presented by reference 62 show that the concentration of PCDDs and PCDFs in fly-ash particles collected by a fabric filter (baghouse) is larger than that found in fly-ash particles collected by a dry scrubber, and the latter is larger than the concentration on fly ash particles collected by wet/dry scrubber. Baghouses are considered as having one of the highest particulate removal efficiencies. This ability to collect very fine particles could reduce discharges of PCDD and PCDF fly-ash particles into the air but could increase the potential for higher leachability of these contaminants into surface and groundwater resources.

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